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THE DEVELOPMENT OF A CONTINUOUS MULTIPARAMETER WATER QUALITY MONITOR

ARKANSAS UNIVERSITY, LITTLE ROCK

PREPARED FOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
WASHINGTON, D.C.

AUGUST 1969

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THE DEVELOPMENT OF A CONTINUOUS MULTIPARAMETER WATER QUALITY MONITOR

Department of the Interior
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A monitor for recording various parameters indicative of water quality was designed, constructed, and field tested. This water quality monitor was built to meet the requirements of complete portability; operation where no line power is available; long-term unattended operation; monitoring capability for 4 to 8 parameters; using "off-the-shelf" equipment where possible for minimum construction cost; and computer compatibility of data readout. During the latter portion of the work, the state of the art of integrated circuits advanced appreciably with an attendant decrease in cost of operational amplifiers and other electronic functional components.

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ERRATA

THE DEVELOPMENT OF A CONTINUOUS MULTIPARAMETER WATER QUALITY MONITOR

Pages xx and xxi are transposed: page xx should be xxi and page xxi should be xx

Page 39, line 4 should read: "... a freshly charged battery..."

Page 67, the third line from the bottom should read: "... the scattered light is received at detector 2."

THE DEVELOPMENT OF A CONTINUOUS MULTIPARAMETER WATER QUALITY MONITOR

Department of the Interior
Federal Water Pollution Control Administration
Research Grant WP 00044

August 1969

Department of Electronics and Instrumentation
University of Arkansas Graduate Institute of Technology
Little Rock

MK Testerman

M. K. Testerman
Principal Investigator

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Abstract Of The Final Technical Report On

THE DEVELOPMENT OF A CONTINUOUS MULTIPARAMETER WATER QUALITY MONITOR

A monitor for recording various parameters indicative of water quality has been designed, constructed, and field tested. This water quality monitor was built to meet the requirements of complete portability; operation where no line power is available; long-term unattended operation; monitoring capability for 4 to 8 parameters; using "off-the-shelf" equipment where possible for minimum construction cost; and computer compatibility of data readout.

The monitor components, including power supply, recorder, and sensing circuitry are housed in a 12-foot flat-bottom boat provided with a protective cover. The boat is divided into two compartments: one containing the source of electrical power and the other containing the sensing, signal conditioning, and recording equipment. There is also space in the boat for a person to stand and service the equipment as needed. The boat constitutes a part of the monitor design and permits launching or towing of the monitor to an otherwise inaccessible area in a river or lake where the unit can be anchored for recording water quality parameters.

The system design is such that the transducers operate in situ so that no pumped sample is necessary. The power supply for the system consists of a gasoline motor generator set, two automotive type lead-acid storage batteries, and a DC to AC converter. The batteries are recharged by the generator when the charge level in the batteries reaches a preset value.

This model has been field tested for recording values for the temperature (±0.1°C) of the water being monitored, the dissolved oxygen content (within 0.2 parts per million), the conductivity (±1%) and pH (within ±0.1 of 1 pH unit) and the temperature inside the boat itself. Provisions for measuring chlorides and redox are also available. The magnitude of the various parameters is recorded on foil-backed paper tape in binary coded decimal format. This tape is computer compatible so that tape from the field can be subjected to data reduction processes without intermediate translation. The recorder can register variations as small as one part in 10,000 with an accuracy of ±1/2 of one bit. In comparing the recorded readings with grab samples analyzed in the laboratory, little deviation was apparent for any given parameter.

During the latter portion of this work the state of the art of integrated circuits advanced appreciably with an attendant decrease in cost of operational amplifiers and other electronic functional components. Also, dissolved oxygen electrodes have been developed with lifetimes of reliable operation approaching six months. These developments need to be incorporated in the design of the monitor. Even so, the monitor's performance is significant when compared with other existing monitoring systems.

A Summary of the Final Technical Report on

THE DEVELOPMENT OF A CONTINUOUS MULTIPARAMETER WATER QUALITY MONITOR

Department of Electronics and Instrumentation
University of Arkansas Graduate Institute of Technology

I. INTRODUCTION

The following is a summary of the work performed by this laboratory involving the research, development, design and construction of a water quality monitor. Long range goals set at the beginning of the project included: the ability to operate at sites where line electrical power was not available; complete portability of the monitor; minimum cost compatible with satisfactory performance; capability of monitoring 4 to 8 parameters; the use of as much off-the-shelf equipment as possible in order to reduce construction cost; data readout compatible with computer input devices; and emphasis on long term unattended operation.[*]

Requirements exist for an instrument of this type; first, for remote locations where a monitor needs to be installed with short lead time; second, for monitoring streams in locations where no permanent monitor is desired as a means of ascertaining the ability of a stream to absorb additional pollution when industrial plant site planning is involved; and third, where estuaries present problems in installation of permanent power facilities. In many cases, permanent locations in these estuaries are not desirable because of shifts of alluvial deposits. For these reasons, this monitor was not provided with the customary sample pumping facility which would allow the installation of the main portion of the instrument on shore.

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[*] Testerman, M. K., Borchers, C. E., Raible, R. W., and Romine, R. W., "A Self Contained Water Quality Monitor", presented before the Div. of Water and Waste Chemistry, American Chemical Society, Philadelphia, April 5-10, 1964.

Figure A shows the monitor housing and trailer-rig which was devised for making a self contained portable unit. The complete monitor (transducers, signal conditioning, programmer, and recorder) can be placed in operation in a chosen location by floating it from the trailer and anchoring it in position. The cover over the boat insures weather-proofing as well as reducing vandalism.

The 12 foot Jon boat will accommodate the approximate 300 pound weight of the complete monitor plus 20 gallons of gasoline and still allow one person aboard in either compartment to perform maintenance and repairs (Figures B1 through B4). Figure C shows the complete monitor in operation. The gas tank is mounted in the rear of the boat with a partition between it and the motor generator. A solid panel divides the forward and rear wells and provides mounting for the controls (Figure D). The electronics package which contains all of the programmed switching, signal conditioning, and recording circuitry is mounted in the forward well. The transducers are attached to the bow of the boat and extend into the water to a depth of approximately one foot (Figure E).

A block diagram of the system (Figure F) indicates three sections that can be discussed individually. These are the transducers and their input circuitry; the signal conditioning and recording circuitry; and the power supplies.

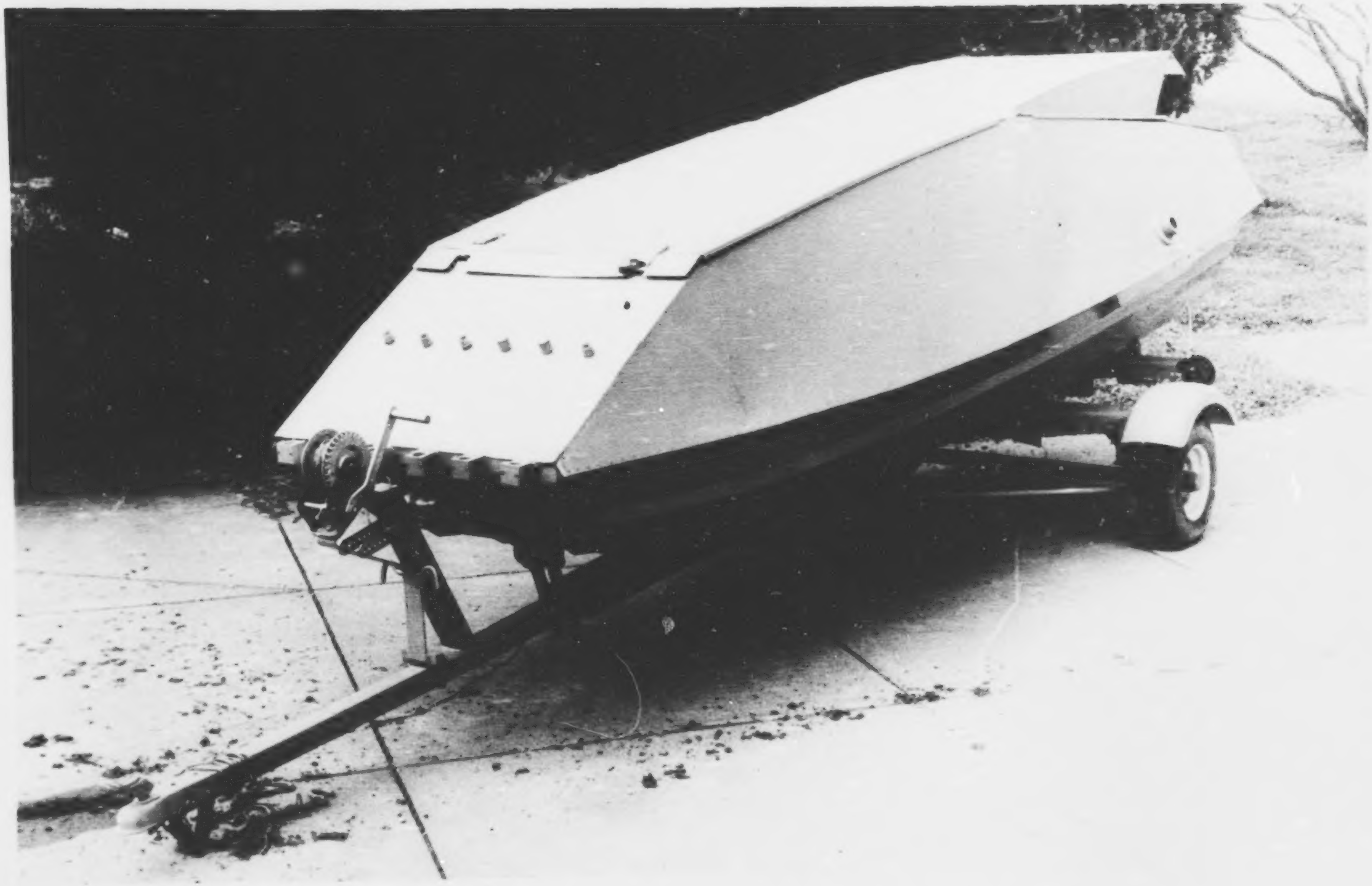


Figure A. Mobile Monitor

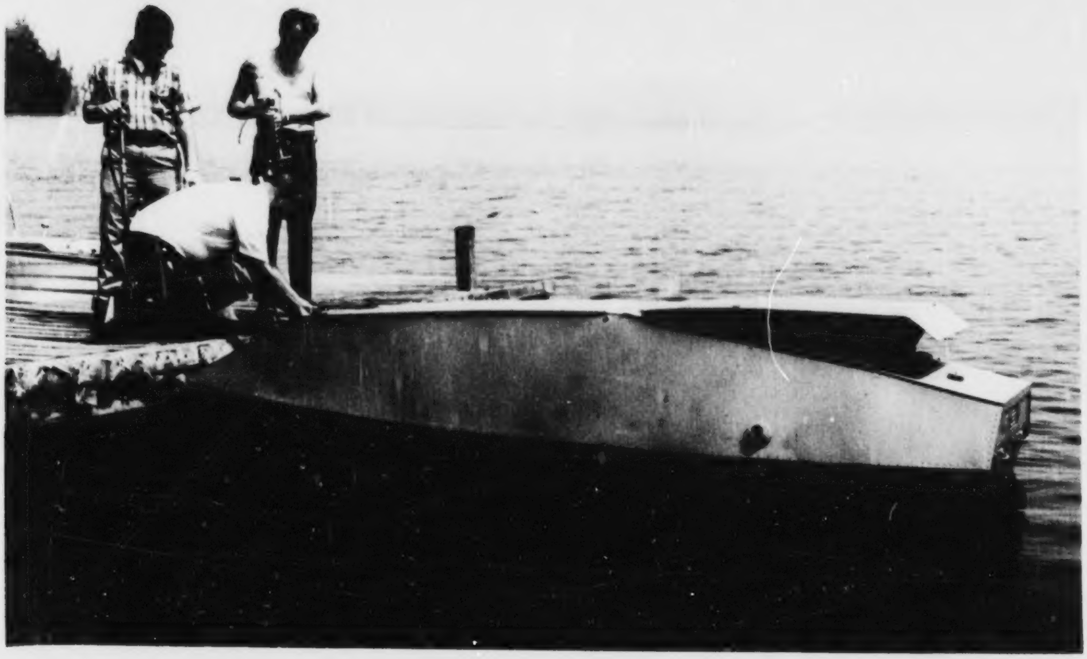


Figure B1

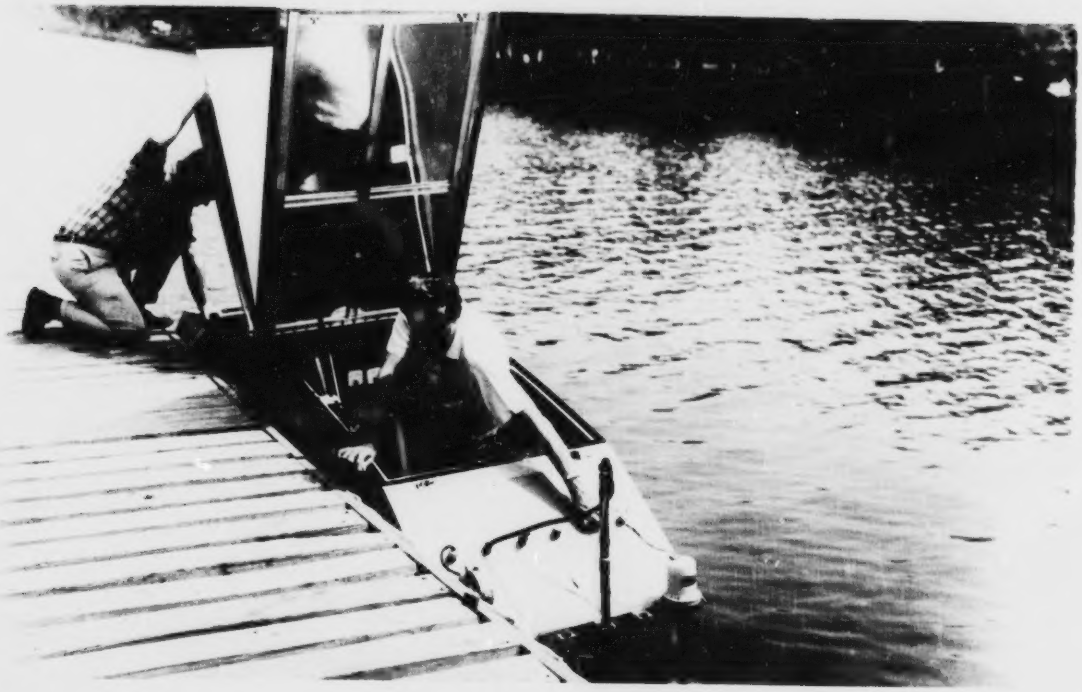


Figure B2

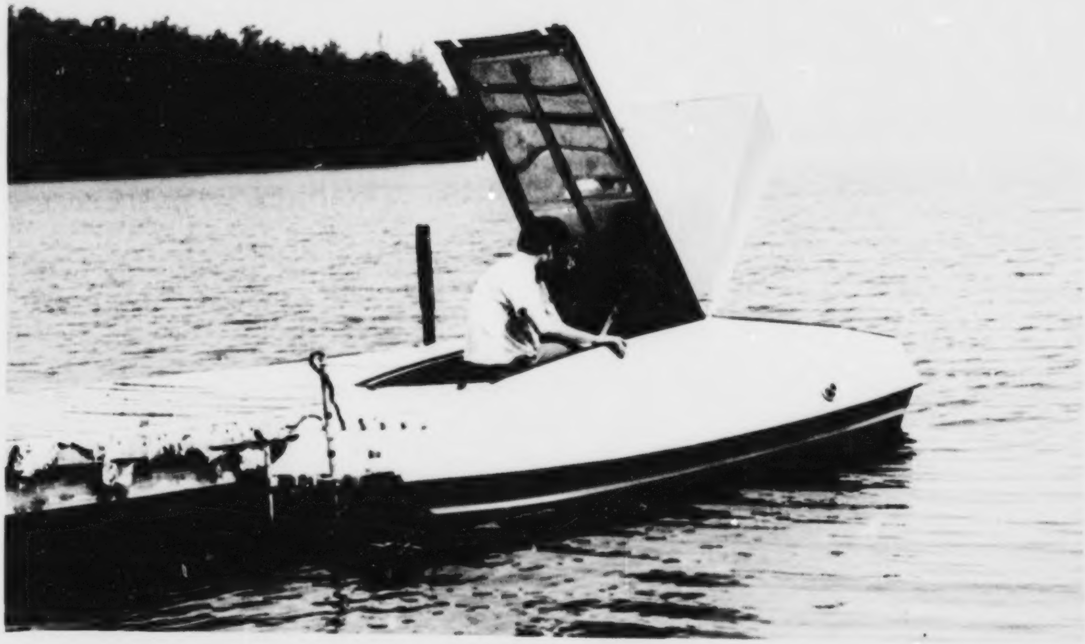


Figure B3

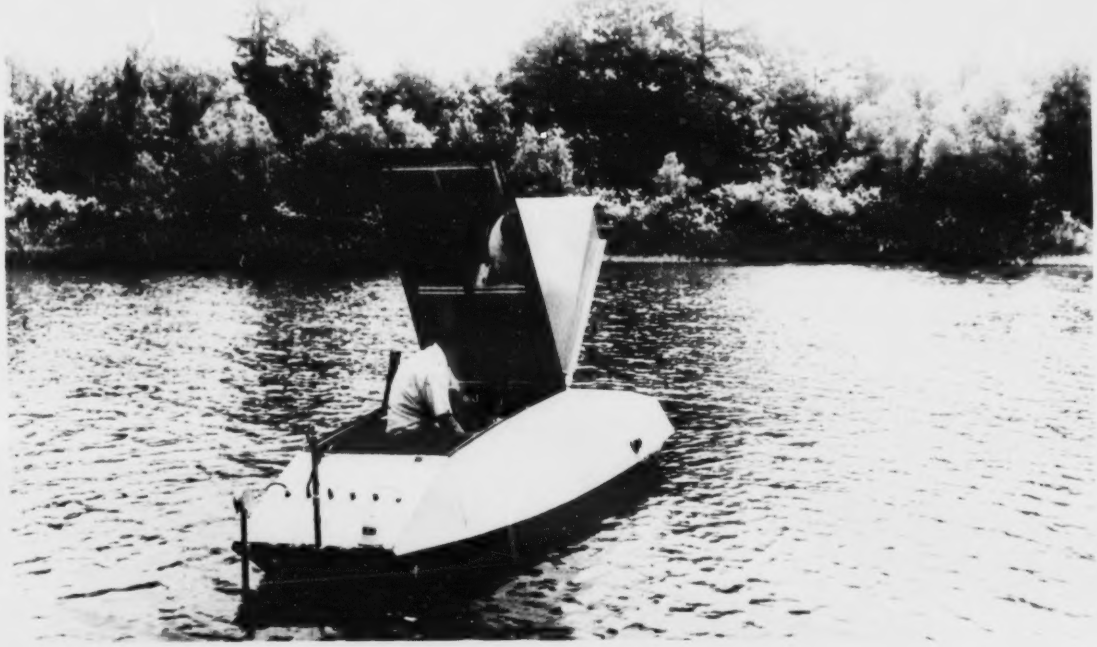


Figure B4

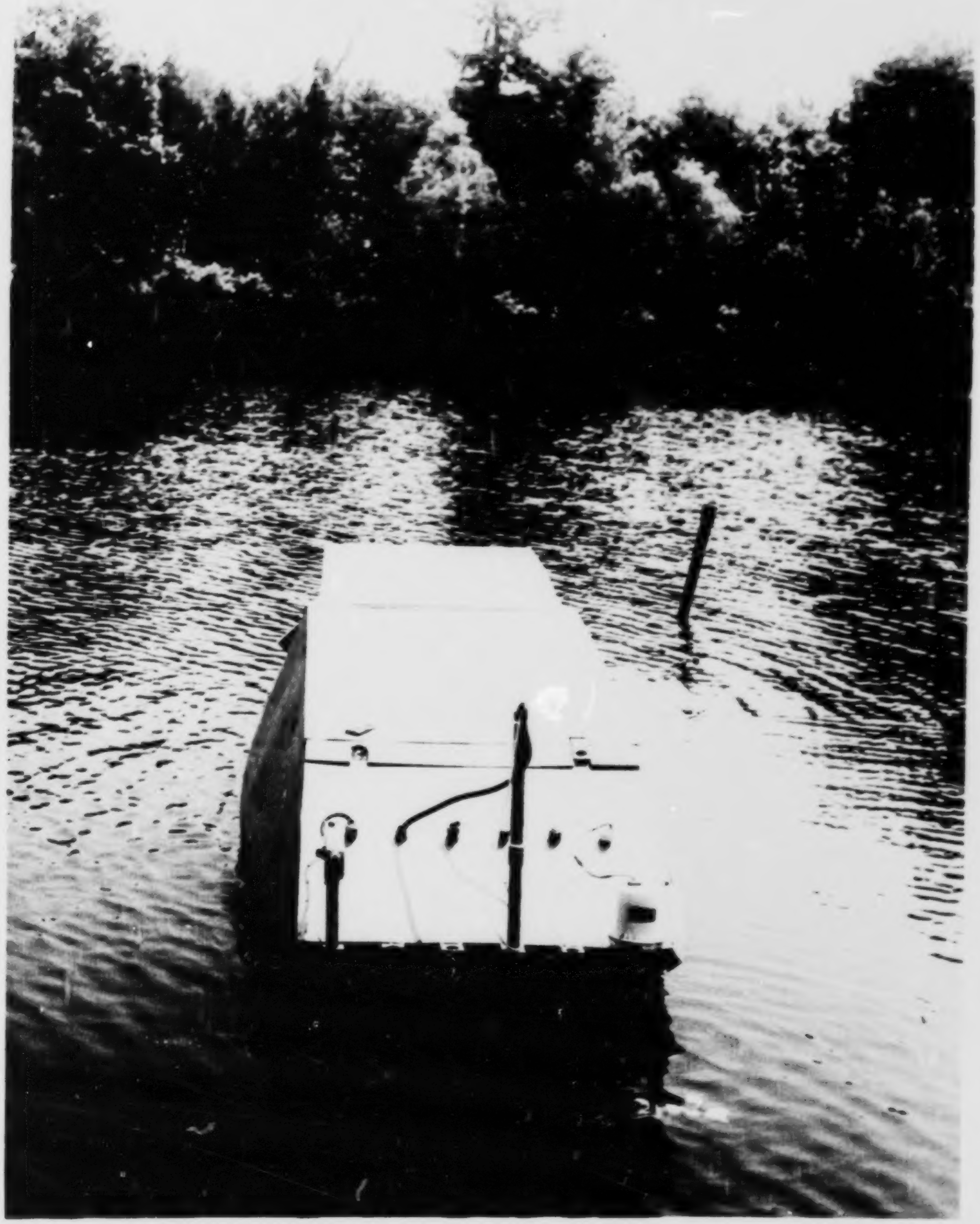


Figure C. Monitor in Operation

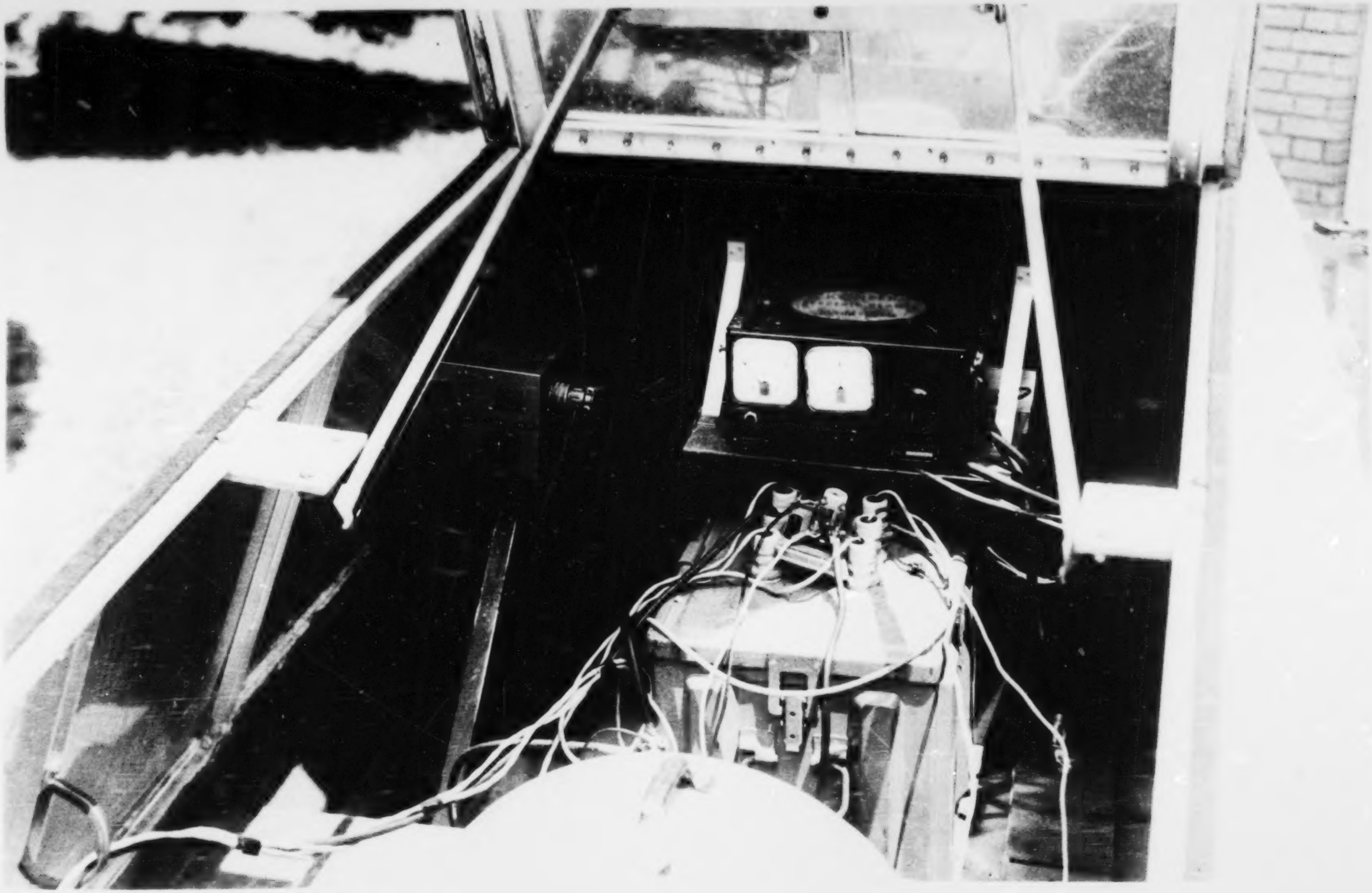


Figure D. Control Panel

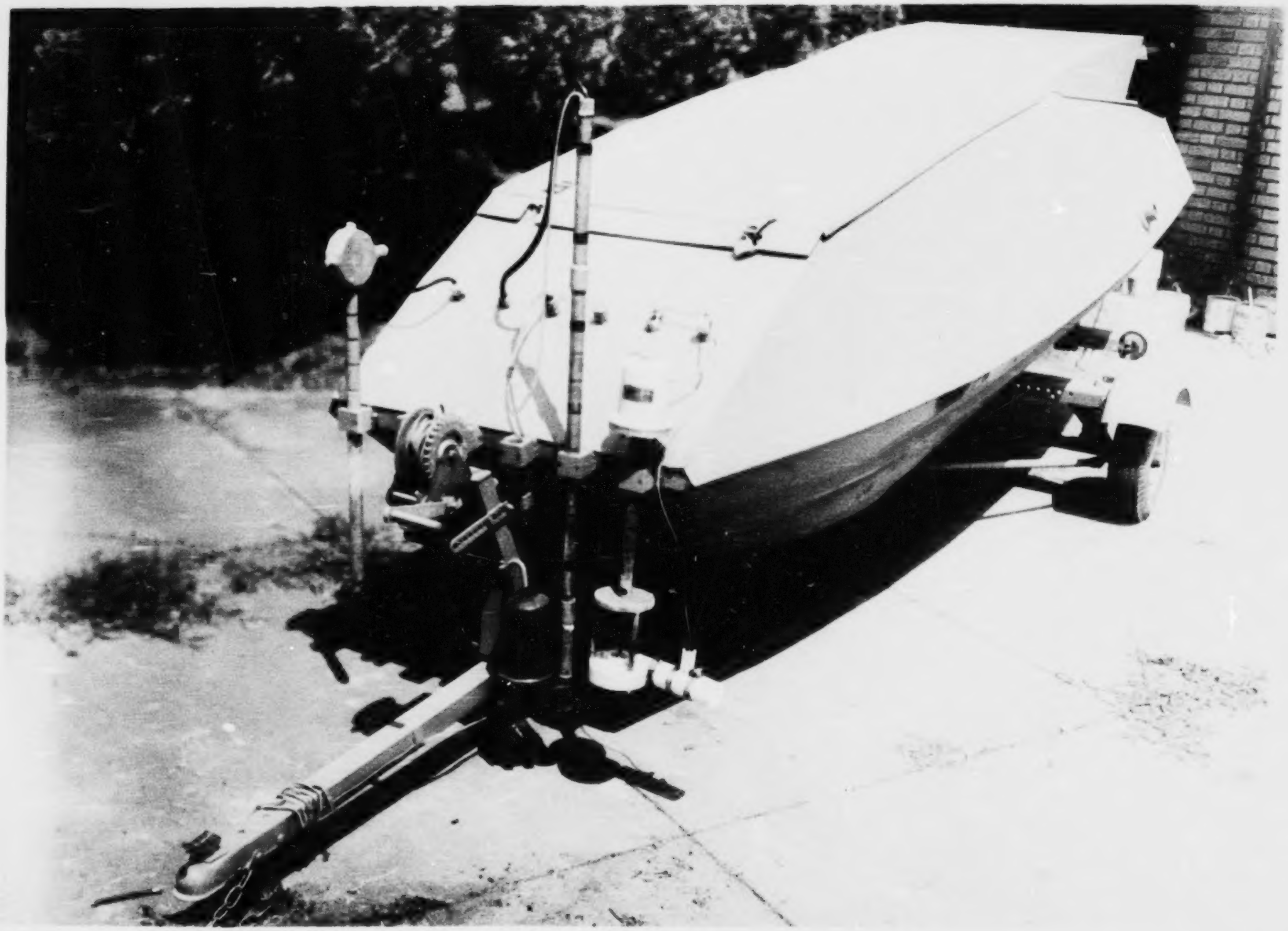
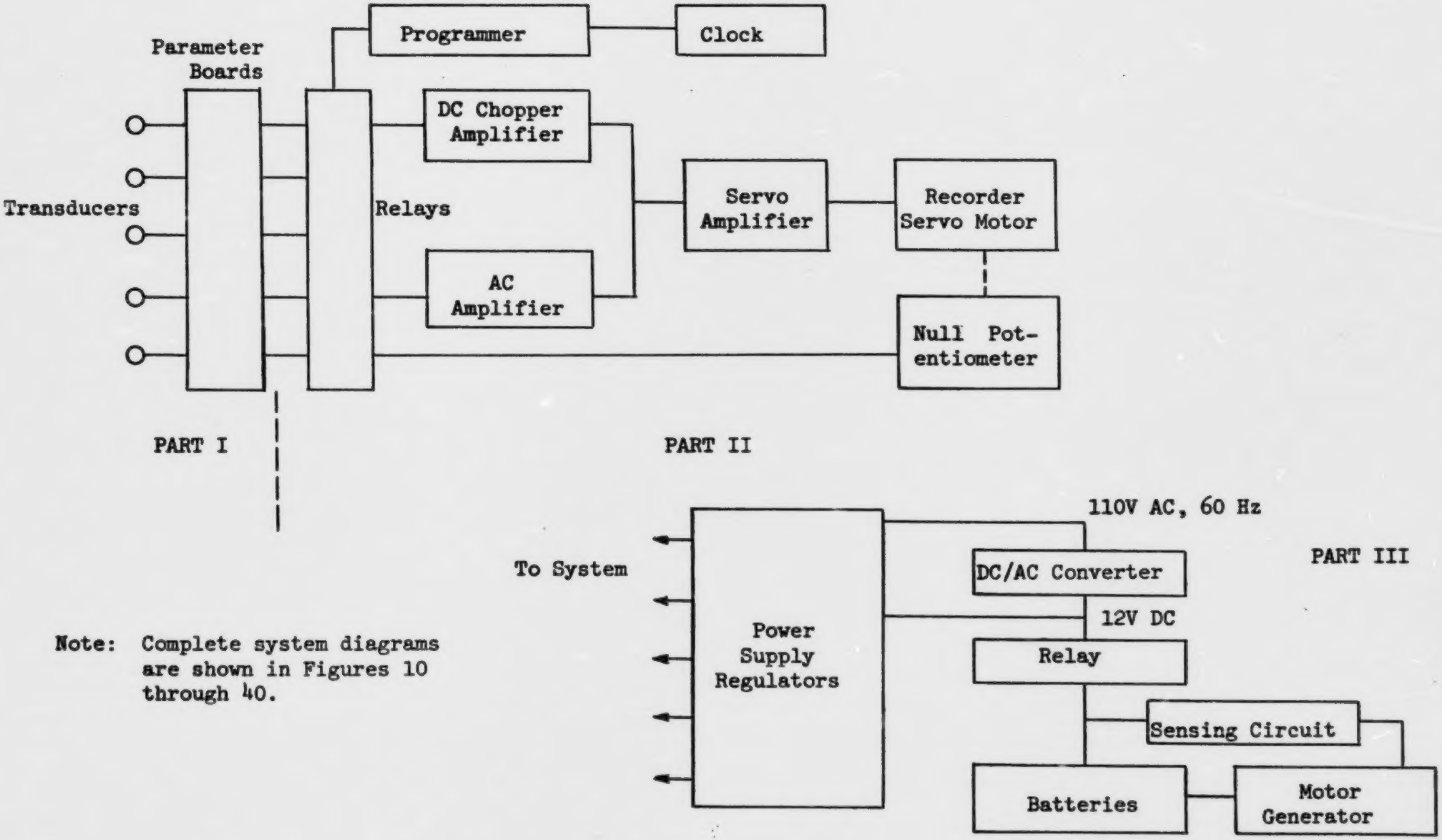


Figure E. Monitor with Transducers Attached


Parameter Boards
Programmer
Clock
DC Chopper Amplifier
Transducers
Relays
Servo Amplifier
Recorder Servo Motor
AC Amplifier
Null Pot-entiometer
PART I
PART II
110V AC, 60 Hz
PART III
To System
DC/AC Converter
12V DC
Power Supply Regulators
Relay
Sensing Circuit
Batteries
Motor Generator

Note: Complete system diagrams are shown in Figures 10 through 40.

Figure F

System Block Diagram

This instrument evolved over a seven year period with the final field tests being completed the latter part of 1968. Much of the system progressed with the "state of the art" until the design of the various subsystems had to be frozen.

Initial field tests were performed on the prototype in 1964 and 1965. Modifications and a small amount of redesign allowed a usable device to be fabricated and field tested fairly extensively during the following two years. Continual updating of the system where it did not require major design changes has been done and at the present time continuing studies on dissolved oxygen transducers are being performed with emphasis on longer lifetime devices.

SYSTEM DESCRIPTION

Part I of Figure F shows schematically the individual transducers with the input circuitry associated with each of them. Part II is the amplifying and switching circuitry, the programmer, clock, and recording circuits. Part III contains the power supplies, batteries, and motor generator.

The input circuitry, associated with certain parameters, utilizes AC excitation in bridge-type circuits where one leg of the bridge is a potentiometer which is coupled to the servo motor in the recorder. The error voltages from these bridge circuits are sequentially switched through a set of reed relays into the amplifier chain. The switching is initiated by a cam-type programmer (Figure G) which is manually adjusted to allow approximately thirty seconds for each measurement. The error voltage is amplified and fed to the servo amplifier which in turn applies a signal to the control winding of the servo motor. The servo motor then drives both the recorder and the potentio-

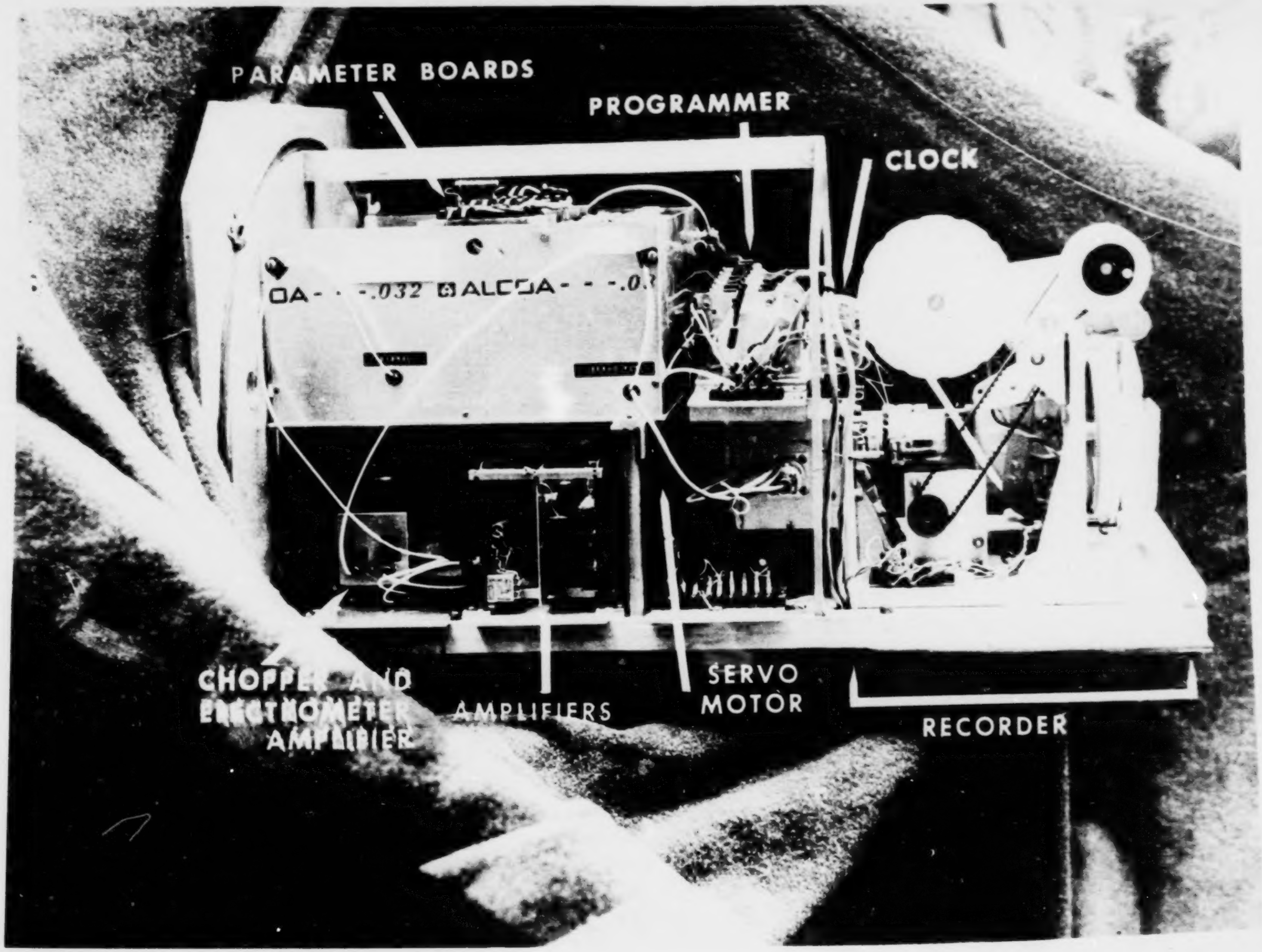

PARAMETER BOARDS
PROGRAMMER
CLOCK
OA - - .032 ALCOA - - - .03
CHOPPER AND ELECTROMETER AMPLIFIER
AMPLIFIERS
SERVO MOTOR
RECORDER

Figure G. Electronics Package

meter to the position where the voltage across the potentiometer is equal to the input voltage from the transducer. The recorder records this position and the cycle is repeated for the next channel.

The parameters which utilize DC excitation apply their signal voltage to one side of a chopper at the input of a high impedance electrometer amplifier. The other side of the chopper has the DC reference voltage applied to it by the servo potentiometer. The error voltage is amplified by the electrometer amplifier and fed into the amplifier chain and servo amplifier as described previously. In this measurement, the servo potentiometer is utilized as a voltage divider with the output being the reference voltage. The chopper operates at 60 Hz so that the error signal is in a particular phase relationship with the reference winding of the servo motor.

The null-balance method of measurement is used in this system to eliminate the necessity of very precise linear amplifiers. This allows the use of diode limiters on the output of the high gain amplifiers in the signal path to prevent overloading and recovery time delays. The use of an AC system was determined by a number of considerations. One of the most important of these was the fact that AC servo motors were readily available and less expensive than DC types. Also, the conductivity measurement requires an AC excitation as a means of preventing electrolytic polarization effects. The high impedance DC measurements, such as the pH, lend themselves very well to the application of choppers and high impedance amplifiers since this tends to eliminate drift problems which are prominent in high impedance circuits of this type.

The operational cycle frequency of the monitor is controlled by an electrical clock made by Geodyne Corporation, Model No. A-782. It operates a switch which energizes the programmer at preset time intervals. These time intervals can be adjusted by changing cams in the clock such that periods from 10 to 60 minutes can be obtained. This method of timing was chosen since it offered the most versatility and accuracy for the least cost of any device obtainable.

TRANSDUCERS

The transducers used in this monitor are all commercially available devices which proved to perform satisfactorily through extensive testing and operation. A significant amount of work was done at the beginning of the contract in attempting to develop a long life dissolved oxygen electrode.* This dealt primarily with a polarographic electrode using pyrolytic carbon as a cathode.

The dissolved oxygen electrode used is a Beckman Model No. 76365 Polarographic Oxygen Sensor. It requires a stable polarizing voltage of approximately 0.7 volt applied to it at all times. The current through the probe is a function of the oxygen content of the water. A voltage signal is developed by passing this current through a 50 Kohm resistor. This voltage is compared to the voltage across the servo potentiometer which is driven by the servo motor until they are equal. The electrode current is in the range of one to two microamperes. The oxygen electrode requires a minimum of 1-1/2 ft/sec flow rate across its face and necessitates a small pumping mechanism (Figure H) to insure sufficient water velocity.

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*R. W. Romine, "A Polarographic Dissolved Oxygen Transducer with Pyrolytic Carbon Cathode", M.S. Thesis, U. of Arkansas, 1966.

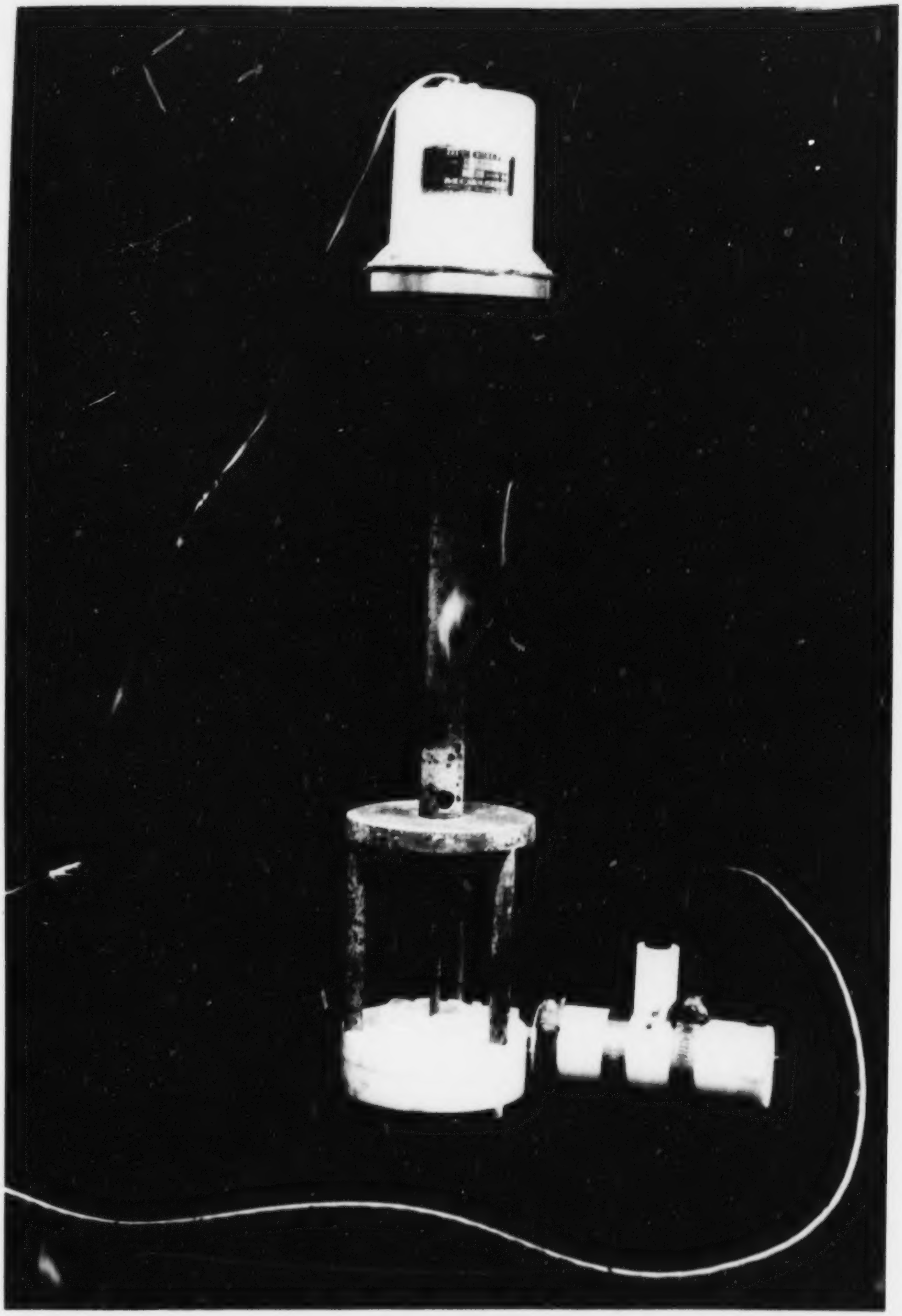


Figure H. Dissolved Oxygen Electrode and Pumping Mechanism

The pH electrodes used are the Beckman Glass Electrode No. 19500 and the Reference Electrode No. 19550. The measurement of pH involves a voltage measurement which has both positive and negative values. The output of the pH probe is approximately 59 millivolts per pH unit. The pH electrode is a high impedance device which requires particular care to eliminate pickup and ground loops in the circuitry. The insulation resistance of all wires and connections must be extremely high. The output voltage of the pH probe is applied to the chopper and electrometer amplifier in the same manner as the dissolved oxygen voltage.

The temperature measurement is accomplished by use of a Beckman Thermo-Compensator Model No. 19580. It is a resistance thermometer made of Driver-Harris High Tempco metal and has approximately 4,000 ohms resistance at room temperature with a change of approximately 14-1/2 ohms/°C. This particular unit is available with the pH probe for use in temperature correction of the pH measurement. The resistance thermometer is used as one leg of an AC null-balance Wheatstone bridge where the servo potentiometer is in another leg of the bridge. Care must be exercised to insure that the excitation to the bridge is not large enough to cause any self-heating within the resistance thermometer. The temperature measurement is important since both dissolved oxygen and pH require a temperature compensating factor in their determination.

The conductivity transducer that is used is an Industrial Instruments Incorporated Dip-Type Conductivity Cell Model CEL-VK. Various cell constants are available to meet the requirements of the water that is being monitored. The conductivity probe is utilized in an AC-Wheatstone bridge in much the same way as the resistance thermometer. The conductivity measurement must use an AC excitation voltage since polarization effects would occur at the electrodes if DC voltage were used.

RECORDER

The recorder which was incorporated into the system is a Fischer-Porter Analog to Digital Recorder, Series 1542 (Figure I). This is a reasonably priced device which gives a punched tape readout in Binary Coded Decimal form (Figure J) with a resolution of one part in ten thousand. The tape size and format is compatible with commercially available translating systems. The tape utilized with this recorder is approximately 400 feet long and would allow recording of six parameters at 15 minute intervals for 83 days. Since unattended operation of the system usually would not extend for a time interval of this length, portions of the tape can be removed and returned to the central station for translation. This recorder also provides a visual readout to facilitate calibration procedure and any maintenance problems that may occur. The tape can also be readily translated on-site by an individual who is familiar with the Binary Coded Decimal system.

The computer facility available in this laboratory for data reduction purposes is the ALWAC III-E computer. For compatibility of the Fisher-Porter Recorder tape with the ALWAC, modification of the high speed tape reader designed for reading eight-level paper tape was necessary. An interface unit was designed for the reader permitting the binary coded decimal information from the recorder tape to be read directly into the data reduction program. Parameter values for readings made at fifteen minute intervals over a two-hour period in the test location are shown in Table I. When a diurnal variance is evident for a parameter

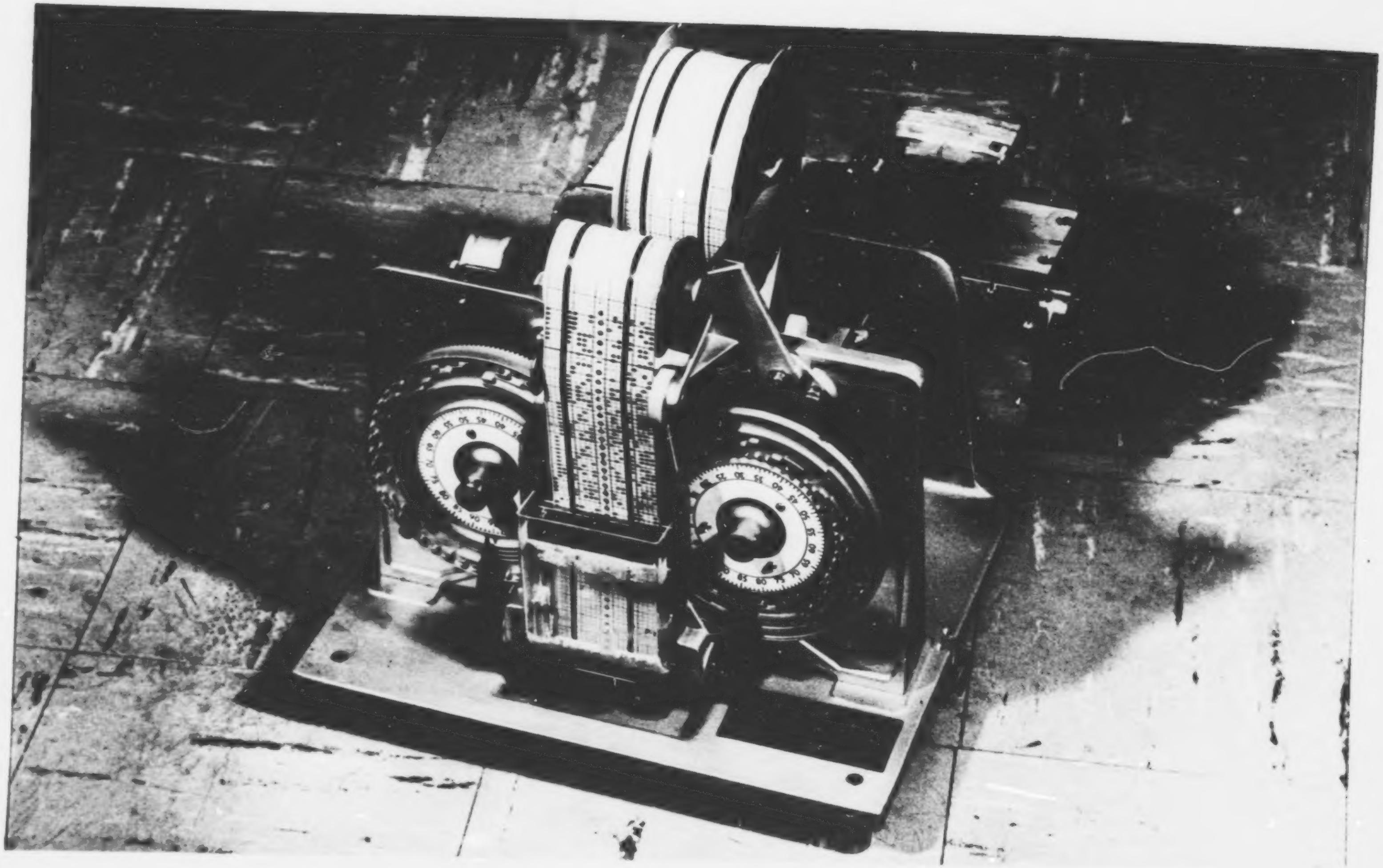
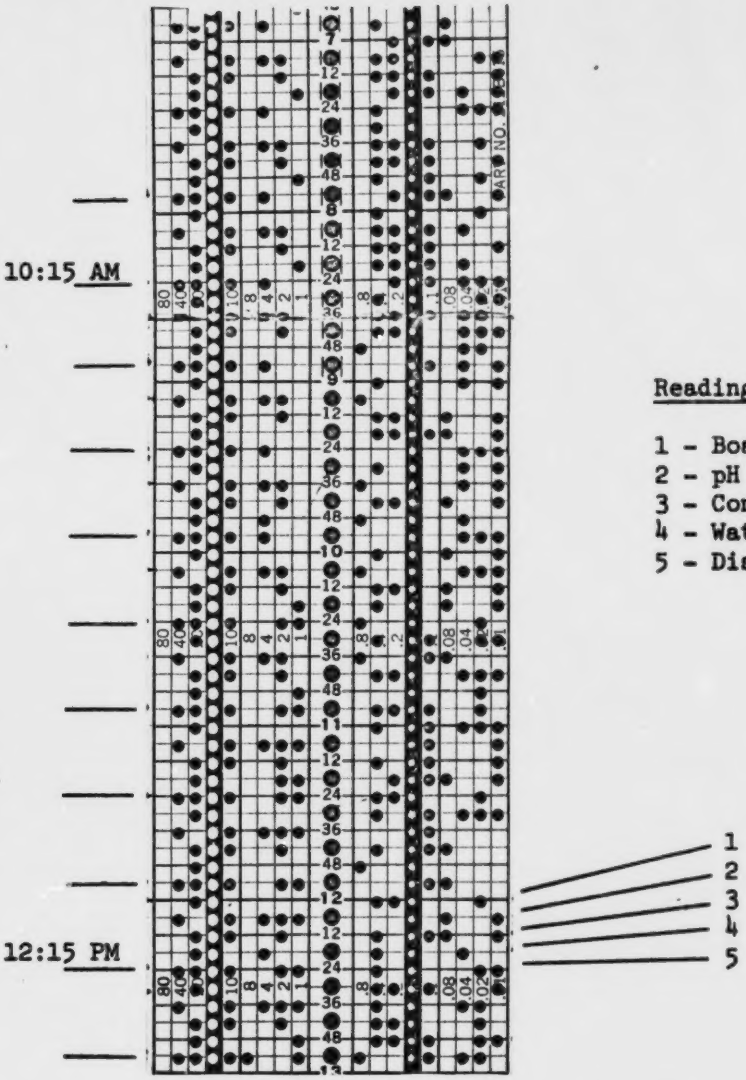


Figure I. Modified Recorder



Reading Sequence

1 - Boat Temperature
2 - pH
3 - Conductivity
4 - Water Temperature
5 - Dissolved Oxygen

Figure J

Typical Data from Unattended Water Quality Monitor it is feasible to suppress print out except on an hourly basis or possibly except for a maximum and minimum reading, dependent upon the application of the information. The print-out format and amount of information derived from the data reduction process is left to the discretion of the user.

Table I

DATA READINGS TAKEN AT 15-MINUTE INTERVALS FOR 2-HOUR PERIOD

Time	T_{water} (°C)	pH	Conductivity ($mhos/cm^3$)	DO (ppm)
10:15 AM	11.58	8.60	325.56	10.64
10:30 AM	11.59	8.61	325.96	10.73
10:45 AM	11.61	8.61	325.96	10.75
11:05 AM	11.61	8.62	325.76	10.75
11:15 AM	11.64	8.62	325.76	10.84
11:30 AM	11:67	8.62	325.96	10.87
11:45 AM	11.70	8.64	327.56	10.90
12:00 AM	11.70	8.64	326.86	11.08
12:15 AM	11.74	8.64	326.76	10.97

Power Supplies

Since one of the major requirements of the system is that it be self-contained and be able to operate for long periods unattended, electrical power generation and storage is critical.

Several possibilities were considered. Among these were solar cells which were expensive and fragile, thermoelectric generators whose useful lifetimes proved too short, and a bank of storage batteries. The power

RESULTS

The magnitudes of the various parameters measured were recorded on paper tape as described previously. The format of the data is Binary Coded Decimal punched out in parallel form such that each parameter reading is displayed in one row which contains four four-bit binary coded decimal numbers. The maximum value possible would be 9,999; thus, the recorder can register variations as small as one part in 10,000 or 0.01% with an accuracy of ±1/2 of one bit. This has been verified in the laboratory. Therefore, the accuracy with which the parameters are recorded is dependent only upon the accuracy of the transducer and the amplifying circuitry. Additional tests have been run which indicate that the amplifying circuitry and servo amplifier provide accuracy comparable with the recorder. This has been done by using a precision decade resistance box on the input of the system in place of certain transducers, such as the resistance thermometer. The recorder can register one ohm changes of the resistance box where 4,000 ohms is set up as mid-scale reading. This indicates that the accuracy of the system is probably limited by the transducers themselves. In laboratory tests, very good results were obtained for all parameters. A true accuracy figure for the system is very difficult to arrive at under field operation but accuracies of the order of the design criteria were obtained. During field tests, the parameters were checked by taking "grab samples" and performing the analysis in the laboratory. In several instances it is believed that the instrument was more accurate than the results obtained from the samples. Temperature can be read to within ±0.1°C.; pH can be measured to within ±0.1 of 1 pH unit; conductivity can be requirements of the system are large enough that a logistics problem results when enough batteries are used for a month's operation. The most feasible solution to this problem was the incorporation of a small motor generator unit into the system to charge two automotive type lead acid storage batteries. The motor generator is a model widely used for standby power by some of the large public utilities (Figure K). It consists of a 4 cycle gasoline engine driving a 12 volt DC electrical generator. The controller for the motor generator is a voltage sensing circuit employing several relays, one of which starts the generator engine when the storage battery voltage decreases to a certain level and another which stops the engine when the batteries are recharged. Two batteries are used so that the large amount of current used to start the generator engine is not reflected into the monitor supply. The complete power supply (Figure F, Section III) consists of the motor generator, DC to AC converter, and the batteries. The 12 volt DC power is applied directly to all circuits which do not require a highly regulated supply. The converter transforms the 12 volt DC into 60 cycle 110 volt AC. Through the appropriate transformation, this power is used for the AC servo and the AC bridge circuits. It is also converted to DC where a highly regulated supply is needed.

Mechanical problems plagued the motor generator from the very beginning and necessitated several modifications. Fail-safe circuits were added to the system to minimize the chance of damage to the sensitive circuitry in the monitor in the event that the motor would fail to start and the storage battery was discharged below a preset level.

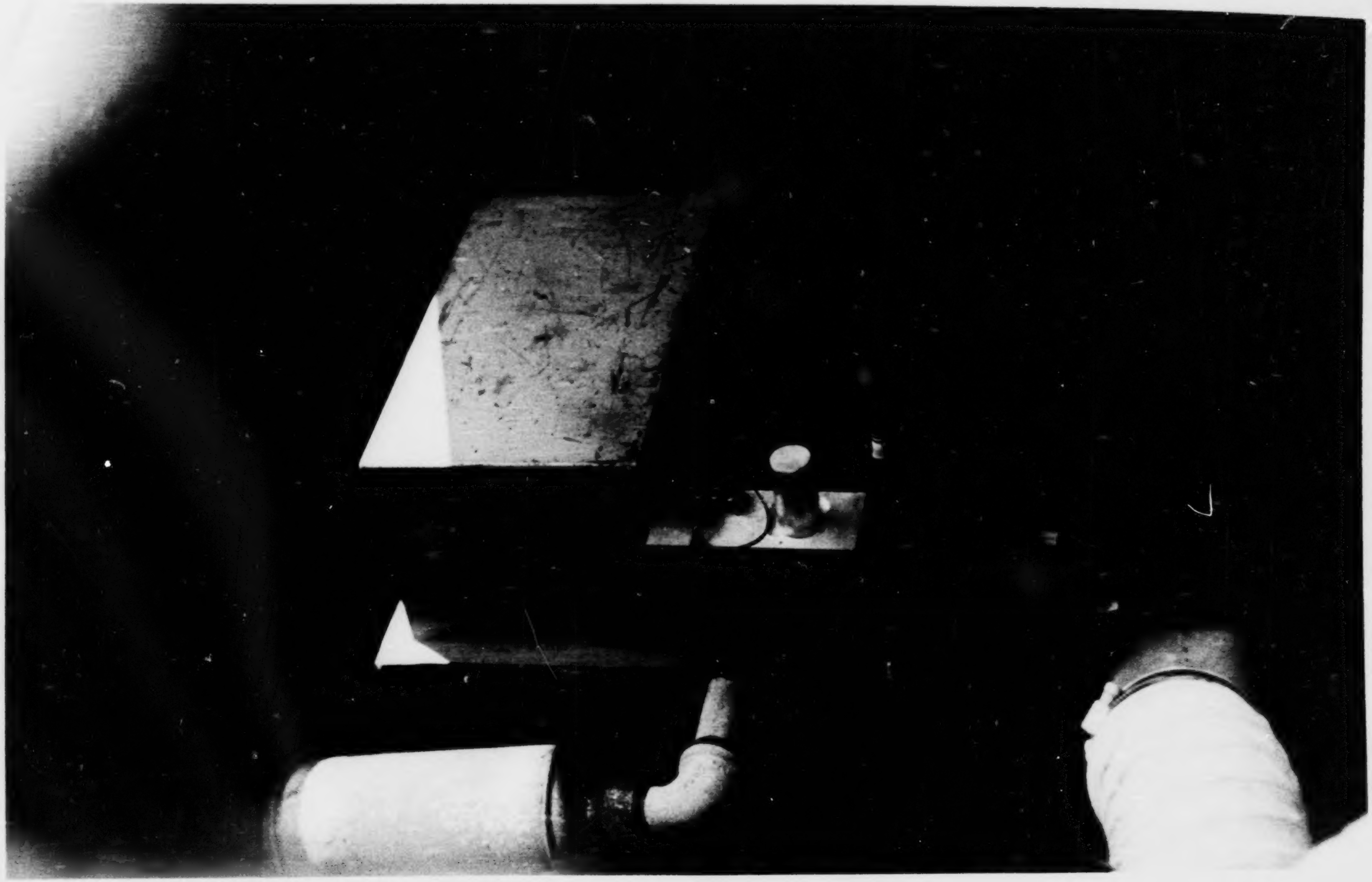


Figure K. Motor Generator

measured to an accuracy of ±1%; dissolved oxygen can be measured to within ±0.2 parts per million. These figures are conservatively estimated values arrived at over different periods of operation of the monitor. Certain restrictions have been imposed upon these figures. These accuracies can be obtained during the first two to three weeks of operation after a complete maintenance check which would include cleaning of all electrodes, and refurbishing the dissolved oxygen probe and the pH probe. No attempt has been made to establish average accuracy figures for a full month's operation, but in general the maximum degradation would be a factor of two to three.

During the development of this instrument numerous problems became evident, such as noise problems in the electronic circuitry primarily due to ground loop troubles, minor mechanical problems with the punch mechanism on the recorder, and several others. By the termination of the contract period, practically all of these problems had been solved except for two, the first of these being the limited lifetime associated with some of the transducers. The dissolved oxygen transducer could not be operated reliably for any period over a month, and sometimes two to three weeks was the limit. The pH probe also tends to give erratic information if algae and other growths build up on it. It also has a tendency to eventually collect moisture within the case even though desiccants are present. Field tests performed on this instrument indicated that the maximum time that the transducers could be expected to perform within the stringent accuracies specified above would be something less than a month. Recent advances in polarographic electrodes indicate that this time period may be significantly extended. The second problem which was never completely solved was the trouble with the motor generator unit. In laboratory testing where the unit was monitored every day and very minor adjustments were made on the motor generator, it operated satisfactorily over extended periods of time. When it was placed in field use where there was no personnel adjustment of the unit, many different problems became evident. The most noticeable one of these was the fact that the voltage sensing circuit which started and stopped the motor generator appeared to be temperature dependent and vibration sensitive. There also were problems in starting the gasoline engine when it was subject to the temperature and humidity variations of the outside world. Many different factors entered into the performance of the motor generator and at the present time it is believed that the motor generator unit is the weakest link in the monitor.

CONCLUSION

During the period of development of this instrument many of the problems that had to be solved were state-of-the-art considerations that were satisfied in what appeared to be a most straight-forward manner at that time. In retrospect, some of these decisions would have been different, but as a whole most of the development took the only aspect which looked feasible. There are two major examples of how various components have advanced during this period. One of these is the operational amplifier. This device is one of the most useful electronic components for instrumentation work that is available. At the time that the design of the electronic circuitry of this monitor was started, the cost of operational amplifiers was a minimum of one hundred dollars; at the present time a comparable amplifier is about ten dollars. Another example of this advancement is in the dissolved oxygen electrodes. At the present time, certain types of polarographic electrodes appear to have lifetimes approaching six months.

There are many positive aspects of this instrument which tend to be overlooked at this time due to the fact that there are instruments of this type commercially available. It should not be overlooked though that this instrument is still very much competitive as far as accuracy, versatility and cost are concerned. It is felt that this instrument has contributed a considerable amount to the knowledge and development of the field of water parameter measurement.

THE DEVELOPMENT OF A CONTINUOUS MULTIPARAMETER WATER QUALITY MONITOR

I. CONSIDERATION OF AVAILABLE TRANSDUCERS

A. Dissolved Oxygen:

The measurement of dissolved oxygen in water quality monitoring is of great significance when one considers the damage which may occur if the oxygen level is permitted to decrease below allowable levels. Reduction of the oxygen level affects the ability of a stream to cope with the influx of contaminants because normal digestive action is reduced. Serious damage to the aquatic life in a stream may result if the oxygen depression extends for sufficient time and the stream or lake may present a problem from the standpoint of the production of undesirable odors resulting from the putrefaction of dead organisms.

The National Technical Advisory Committee on Water Quality Criteria (1) recommends that for diversified warm water biota the dissolved oxygen concentration should be above 5 parts per million (ppm) and in no case should go below 4 ppm. For cold water situations the concentration should be at or near saturation. Spawning areas should not fall below 7 ppm at any time. In consideration of the above, the range of interest of dissolved oxygen concentration extends from values approaching zero concentration to a high which may extend to 20 or 25 ppm.

There are several factors which affect the dissolved oxygen concentration of a particular body of water: total respiration, biological oxygen demand, chemical oxygen demand, atmospheric aeration, photosynthetic oxygen production, temperature, sunlight intensity, turbidity, and stream flow. In general, it may be said that where variation in dissolved oxygen is of interest, values varying considerably above and below atmospheric saturation for a given temperature may occur. Consequently, it seems more straightforward to consider dissolved oxygen levels from a standpoint of parts per million or the equivalent value of milligrams per liter, rather than considering percentage saturation.

Many methods for determining dissolved oxygen have been described in the literature (2). The Winkler Titration analysis (3), which is prescribed in laboratories or in the field where grab samples are taken, is the generally accepted method for measuring dissolved oxygen. However, situations requiring continuous monitoring, such as natural streams, areas of waste water discharge, or sources of public water supply, necessitate the use of a transducer supplying a continuous signal indicative of the dissolved oxygen level. Some of the methods of determining dissolved oxygen do not lend themselves to field applications. Examples of these are the parametric measurement of oxygen, and thermal conductivity methods involving the stripping of oxygen from the solution with a second gas. These methods have been applied where a permanent installation is anticipated.

For field application, electrochemical cells appear to be the most likely method of measuring dissolved oxygen. Many cells are described in the literature (2,4,5,6,7). The galvanic cell (2,6,7) employs a current which is generated by the presence of a highly conductive solution, such as potassium chloride, between a pair of electrodes, (one of which may be zinc, cadmium, or lead as the anode and the other being a gold, silver, or nickel cathode). The galvanic cells were considered for this project because they can be used for on-site measurement and they provide a continuous signal. However, the decay rate of the galvanic type electrodes tested in the early phases of this program was such that the information obtained was of no real value. As is indicated below, improved types have since become available.

Polarographic electrodes (4, 5, 8) require the application of an external voltage which polarizes the electrodes. Current measurements are made, and these currents are directly proportional to the dissolved oxygen content of the solution (2).

Both the galvanic and polarographic electrodes, as normally applied to water quality analysis, are covered with a membrane. This membrane is required to be oxygen permeable and must retain the internal filling solution of the electrode without dilution. Polyethylene and teflon have been found to be the most suitable materials for use as membranes. Since a depletion layer of reduced concentration is produced at the outer surface of the membrane by the action of the electrode, it is normally necessary to provide a minimum flow rate in order to properly measure the dissolved oxygen content of the surrounding solution. In cases such as mountain streams, sufficient water velocity may be available from natural sources. In the areas in which our tests were made, such flow rates could not be anticipated and consequently tests were made to determine the minimum flow rate required. Ordinarily, a flow rate of 1-1/2 ft/sec minimum is required in order to maintain sensitivity independent of flow rate. Flow rates above this figure may be used because the current output signal produced is flow insensitive above this minimum flow level. Thicker membranes require less flow rate to reach the flow plateau. Also, if particularly vigorous stirring or turbulent flow is directed against the face of the electrode, the output signal may contain fluctuations which could influence the reading of instruments which sample during a very short time interval. These fluctuations will produce an output from the electrode which appears to be noisy.

An added complication involving both the galvanic and the polarographic electrodes is that produced by temperature variation of the water. This variation of current output with temperature is largely caused by membrane characteristics. There are also secondary temperature effects of the electrode reaction and electrode potential; however, in comparison to the temperature coefficient produced by the membrane, these other effects may be considered negligible (2). In some cases, compensation of the membrane sensitivity is done by introducing a non-linear compensation network into the amplifier circuitry being used with the electrode. An alternative is simply to measure the current and determine dissolved oxygen from a graph. Such a graph, indicated in Figure 2, is obtained by actual measurement of the current output of the cell using at least three different temperatures, with the determination of oxygen being made with a Winkler Test in the laboratory. It seems probable that, as better methods of mounting membranes on the electrodes become available, it may be possible to use a graph as in Figure 2, hereafter referred to as a Ø-curve, for a given electrode without plotting the curve except at the initial installation. The use of this initial 0-curve can hold only if a consistent source of matching membranes is available, and at least one test must be made to determine whether the sensitivity of the electrode surfaces has changed from the time of initial calibration.

Separate effects seem to be responsible for the degeneration of the two types of membrane electrodes. The presence of CO_2 in the water produces an insoluble precipitate in the case of the galvanic electrodes, which reduces sensitivity. Disassembly and cleaning of the electrode surfaces is necessary to restore sensitivity. In the case of polarographic electrodes, the oxygen reaction produces an insoluble coating of silver chloride on the silver anode. It is necessary periodically to use a fine abrasive cleaner to remove this deposit. It has been found desirable in the case of all of these electrodes, when preparing them with fresh membranes, to wait at least 24 hours, and preferably 48 hours, before performing calibration, since a decided change in sensitivity occurs during the first period of operation.

A considerable number of measurements were made in the field and in the laboratory using the polarographic electrode obtained from Beckman Instruments. Similar electrodes are available from Yellow Springs Instruments and other manufacturers. In most cases, satisfactory operation could be maintained for a period of approximately three weeks with some successful runs extending over a month. A continuous decaying output current is experienced during this period of time, and for most accurate measurements, compensation should be made for this decaying current as the data are reduced.

Recently, electrodes of both the galvanic and polarographic type have become available which hold promise for longer lifetime. The galvanic electrode presently under test is patterned after that of Mackereth (6) and consists of a cylindrical perforated outer shell combined with a large inner lead anode. The membrane in this case is tubing which is slipped over the electrode and sealed with multiple O-rings. It would appear that the massive electrodes suppress the effect of decay with time. Lifetimes varying from two months to one year have been reported by users in the water quality field. We have no figures from these users to indicate the decay rate or accuracy of the measurements obtained.

In the polarographic area, an electrode possessing larger electrode surfaces has been made available by Beckman Instruments. Tests presently being made with this electrode indicate that it also possesses increased lifetime. Reported lifetimes compare with those of the galvanic electrode quoted above.

Studies of less conventional modes for operation of polarographic oxygen electrodes have been performed in this laboratory(9). One of the major problems involved in the measurement of dissolved oxygen at remote sites where power lines are not available is the necessity of providing stirring or flow rate past the membrane of the conventional dissolved oxygen electrode. Thus, studies were initiated to see if measurement of dissolved oxygen would be possible by pulsing the electrode for short periods of time, with the hope that relationships between current measured during this pulsed interval might be related to the dissolved oxygen in the water. Details of this procedure are given in a paper in press (10). In this paper, it was shown that it is indeed possible to measure the dissolved oxygen without necessity for flow or stirring. The current voltage relationships are shown in Figure 3. The voltage applied to the cell should be that normally used for the same electrode when it is used in a flow type situation. The current is related to the dissolved oxygen for several seconds, and it is possible to use the current determined by this method to measure the oxygen.

Initial measurements were made at 1.2 seconds and at 3 seconds after the application of voltage to the cell. Measurements were not made at periods less than 1.2 seconds in this early study because of limited response of the recorder used. The current in both cases was shown to be directly related to oxygen concentration. When variations in temperature are encountered, it is also necessary to plot a correction curve similar to the customary Ø-curve used with conventional polarographic oxygen electrodes.

The cell becomes sensitive to flow when the observation time is extended to periods considerably past those used in this study. For periods shorter than 4-1/2 seconds, no detectable difference occurred in the reading obtained from the electrode regardless of whether or not flow was taking place past the face of the electrode. In this initial study, no information was taken for times less than 1 second after the application of voltage because of the difficulty of measurement involved at the time.

It is necessary to allow the cell to equilibrate between measurements. Complete equilibration at 25°C occurred in 20 minutes, and 99% equilibration occurred in five minutes. The work from this point has been carried on by Mr. Phelps (11).

Tests were made at intervals below 1 second, and it was found that Cottrell's equation does not hold for such short times. It was also found that, for measurements between 1 and 4 seconds, a ϕ-curve can be obtained for temperature which is analogous to the curve used for steady state operation of the probes. Integration of the current from 1 to 4 seconds was used to measure dissolved oxygen and may prove more satisfactory under some circumstances. There is an inherent noise level fluctuation of the current produced, and integration averages out these fluctuations.

A polarographic dissolved oxygen electrode using a pyrolytic carbon cathode was constructed by Mr. Richard W. Romine(12) as part of the thesis requirement for his Master's degree in this department. Mr. Romine demonstrated that pyrolytic graphite could be used as the cathode of a polarographic oxygen electrode. The electrodes which were constructed had cathode areas considerably larger than those of the gold types available at that time. Since it was demonstrated that these larger cathodes produced much larger currents, one could use thicker membranes covering the cathode and still retain sufficient current for a useable electrode. If these thicker membranes were to be used with the small gold cathode type structure, the residual current would be very small. The advantage of the thicker membrane, besides being more rugged, is that the sensitivity to flow is reduced drastically. This fact would prove advantageous where one is attempting to reduce the amount of power required to produce sufficient flow rate across the electrode, and it would also reduce the amount of silt and dirt which is pumped through a system in order to produce the required flow rate. These electrodes had lifetimes exceeding one month. At the time they were constructed, this lifetime compared quite favorably with any of the electrodes which were available. As an example, one of the electrodes which produces 1.75 microamperes at 25°C in air-saturated water is flow independent above flows of 0.1 feet per sec (Figure 4).

B. pH

Measurement of pH in water quality studies is significant because it indicates the acidity or alkalinity of the stream under consideration. Therefore, pH is an inferential measurement since the pollutant is not identified by the pH value, but the level of acidity indicates that pollution has affected the water.

Specifications for a pH monitoring system for use in naturally occurring waters have been set forth by the Federal Water Pollution Control Administration. In its report, "Specifications for an Integrated Water Quality Data Acquisition System" (13), the following specifications are given. "The pH parametric system shall have the capability for measuring an influent between 0 and 12 pH units. The accuracy of the system shall be within ±0.1 pH units between pH 2 and pH 12."

pH is defined as the negative logarithm of the hydrogen ion concentration (14), or

$$pH = -\log c_H.$$

The practical pH scale extends from 0 to 14 with 0 indicating a highly acid solution and 14 indicating high alkalinity with the middle value, 7, corresponding to exact neutrality at 25°C.

pH is monitored on a continuous basis in water treatment installations and waste treatment facilities. Recently, continuous monitoring of pH in naturally occurring streams has become significant in attempting pollution control, because such monitoring immediately indicates any change in the composition of the stream or body of water.

Most natural waters have a pH range of 4 to 9. The National Technical Advisory Committee on Water Quality Criteria (1) suggests that a summer pH range of 7.0 to 9.2 is most suitable for aquatic plants of greatest food value for waterfowl. The committee also suggests that where coastal waters of tidal tributaries are concerned, no foreign materials should be introduced which would cause the pH to be less than 6.5 nor greater than 8.5 pH units. Acidity or alkalinity, as such, in irrigation water is seldom directly detrimental to crop growth, but water with pH values of 5.5 to 8.5 are normally most desirable.

Measurements of pH can be made either colorimetrically or electrometrically. The colorimetric method requires a less expensive investment in equipment but suffers from severe interference contributed by color, turbidity, high saline content, colloidal matter, free chlorine, and various oxidants and reductants. The indicators are subject to deterioration, as are the color standards with which they are compared. Moreover, no single indicator encompasses the pH range of interest for naturally occurring water. The colorimetric method is suitable only for rough estimations and will not be discussed in detail.

The electrometric method, which is considered the standard, applies the principle of potentiometry. A pair of electrodes, the indicator electrode and the reference electrode, are immersed in a solution. The indicator electrode responds to the hydrogen ion concentration, and the reference electrode provides a constant potential against which the potential of the indicator electrode can be measured.

The hydrogen gas electrode is the standard for indicator electrodes. However, its complexity and the difficulties experienced with it do not satisfy industrial and field requirements. It is, nevertheless, used to reference the performance of secondary indicator electrodes.

The glass electrode, in combination with the reference potential of the saturated calomel electrode, is most often used in pH transducers. The potential of the glass electrode is given by the Nernst Equation:

$$E = E_{ref} - \frac{2.3026\ RT}{F} \log a_H$$

where T is the temperature, R is the gas law constant, F is the Faraday constant and a_H is the hydrogen ion activity. Calculating the potential from this equation, the glass electrode system produces a change of 59.16 millivolts per pH unit at a temperature of 25°C (15).

The equation for the potential of the glass electrode is given as

$$E = E_e + 0.000198T(pH - pH_r)$$

where pH_r is the pH of the reference solution contained with the glass bulb (often pH = 7.0) and E_e represents the combination of junction potentials and the asymmetry potential (14). (The asymmetry potential will be discussed in a later paragraph). When the pH cell assembly is standardized with a reference buffer solution, pH_s, the pH is measured by this (16):

$$pH = pH_s + (E - E_s)/0.000198T.$$

Temperature exerts two significant effects on pH measurement: the electrodes vary in potential as a result of temperature variations, and the ionization of the sample varies. The first effect is handled by a temperature compensating element, or, on commercial instruments, an adjustment is provided. The second effect is inherent in the sample system and is taken into consideration by recording both the temperature and the pH of the sample.

The temperature compensator in potentiometric meters changes the resistance in a slidewire circuit such that a change in emf of the cell is correctly converted into pH units at various temperatures. The value (2.3026RT)/F is known as the "theoretical slope" of the curve for pH vs millivolts. Since the slope of the curve is negative, the emf for acid solutions is positive, while that for alkaline solutions is negative.

In practice, the emf of an electrode system may not be zero at pH = 7. This deviation from zero is called the asymmetry potential of the electrode system (Figure 5). The asymmetry potential is not considered to be a function of temperature. The deviation is attributed to the construction and subsequent use of the electrodes which causes unequal conditioning of the active surface of the membrane. Other causes may include composition of the glass, change in water content of the glass surface, and chemical attack on the glass. This deviation is corrected simply by adding or subtracting the voltage necessary to correct the emf to zero at pH = 7. Therefore, the measured potential from a pH electrode system is the sum of the asymmetry potential and the potential due to pH action.

C. Specific Conductance

The measurement of the conductance of a stream of water is a nonspecific measurement since all the ions present contribute to the solution conductivity. However, the level of conductance is indicative of the presence of electrolytes in the stream, thus indicating the water's ability to support life.

Two methods are commonly used for the measurement of conductivity. One of the measurements consists of a so-called indirect measurement where no contact is made with the solution itself. Two methods are available in which electrodes are not exposed to the conducting solution. In one method, operating at radio frequencies, the solution is made to serve as the core of a coil and the Q (loss ratio) of the solution is measured from which the resistance of the solution may be obtained. In the second method of indirect measurement, operating at audio frequencies, the solution in a tube is used to couple a pair of coils. The solution contained in a tube is arranged to serve as a single turn loop, coupling energy from a primary wound around the loop to a secondary which is also wound around the loop. Both of these methods are best suited for solutions of relatively high conductivity, and were not considered to be suitable over the range of conductivities to be measured in this project (17).

The second method for measuring conductivity is a measurement of the resistivity of the water itself made by the insertion of electrodes into the solution. This measurement is usually made by using an A-C Wheatstone Bridge to avoid polarization effects. Polarization effects decrease as the frequency is increased and bridges using frequencies of 400 to 1000 cycles are common. However, many bridges are operated at 60 cycles. Unless very careful precautions are taken, stray capacitance may affect the reading at higher frequencies, and eventually lead to measurements no more accurate than those made at 60 cycles.

Equipment available for conductivity measurements is reliable and, in an unattended water monitor, the measurement of this parameter causes few problems. However, conductivity varies directly with temperature and some of the simpler probes require temperature compensation, either instrumentally or in the data reduction process. Also, conductivity is dependent upon pressure. In naturally occurring streams, however, measurements are made relatively close to the surface so that the pressure dependence may be neglected.

Conductivity measurements are usually made with instruments whose readings give specific resistance in ohms/cm^3. This reading is converted to specific conductance in micromhos/cm^3 (10^6/ohms/cm^3 = micromhos/cm^3) (18). Since conductivity does increase with temperature, the temperature reading is an important part of every record. Several sources have shown that in order to correct a conductivity measurement to a given temperature, it is appropriate to apply a temperature correction factor of approximately 2.5% per degree C (18,19,20).

If it is necessary to know conductivity accurately, the temperature coefficient for the solution being measured must be determined, since it will vary with the composition of the water involved. The values of conductance to be measured vary widely, with the conductance of relatively clean water samples being as low as 30 micromhos/cm^3, whereas, for fresh water streams subject to pollution by oil field brines, conductivity may run as high as 300,000 micromhos/cm^3. Such ranges of values are generally not present in a single stream, and in order to increase the accuracy of the instrument being used, it is customary to change cell constants so that the range of the instrument with its associated cell constant is fitted to the sample anticipated. Cell constants with values from 0.01 to 100 are available which allow a single bridge to be used with a very wide range of samples in optimum fashion. The cell incorporated in the system described herein is an Industrial Instruments Dip-Type Conductivity cell and is described in Section II.

D. Temperature

Water temperature is of primary concern in monitoring water quality because it directly or indirectly affects aquatic life and its environment as well as the rate of chemical and biological reactions. Variation in water temperature also directly affects other parameters of interest.

Not only is it necessary to record temperature simply to have a daily record of the change, but many of the transducers used for monitoring other parameters are temperature sensitive and therefore the changes in temperature must be compensated in making these other measurements.

Several factors determine the temperature of a stream: the diurnal variation, the seasonal changes, and weather conditions. Temperature is also dependent to some extent upon flow rate, depth, and the occurrence of thermal pollution from an industrial plant effluent or from a nuclear power plant which discharges excessively heated water (21).

Acceptable temperature ranges for natural waters quoted in several sources have approximately the same limits. The National Technical Advisory Committee on Water Quality Criteria (1) suggests that fresh water streams and public water supplies have a maximum temperature of $30^\circ C$. However, this does not guarantee that the $30^\circ C$ limit will not be exceeded.

The Federal Water Pollution Control Administration (13) indicates that the parametric system for measuring temperature shall have a capability between $0^\circ F$ and $120^\circ F$. The accuracy of the system shall be $\pm 1^\circ F$ over the entire range.

The choice of a parameter-sensitive transducer is one of the most important problems in assembling a monitoring system. In practice, several popular methods of measuring temperature exist which yield an electrical output (22). A summary of the most useful sensors and their characteristics follows:

1. Thermocouple - The thermocouple is the most frequently used temperature sensor and it provides an accurate and reliable indication of temperature for many kinds of applications. The reliability of the thermocouple is demonstrated by the fact that the platinum versus platinum-rhodium thermocouple is used to define a portion of the international temperature scale. The thermocouples incorporating iron-constantan, copper-constantan, or chromel-alumel elements are satisfactory over the range of natural water temperatures.

2. Resistance Thermometers - These thermometers exhibit greater accuracy than thermocouples, especially in applications necessitating the sensing of relatively small temperature variations. In the laboratory, the resistance thermometer is useful within about the same range as expansion thermometers and some thermocouples. A platinum resistance thermometer is used to define the International Temperature Scale between -300°F and 120°F.

3. Thermistors - These sensors are based on the same operational principle as the resistance thermometer. The thermistor differs slightly from the resistance thermometer in that the wire element is constructed from mixtures of sintered metallic oxides, rather than metal wire. However, the thermistor's response is non-linear so its range is limited; otherwise,

compensating circuitry is required.

In selecting a temperature transducer for an unattended monitor, the primary characteristics of accuracy, stability, sensitivity, speed of response, range, usable life, initial cost and maintenance, simplicity, ruggedness and adaptability to automatic recording must be considered. Only the thermocouple and the resistance thermometer meet all these requirements.

The thermocouple is the simplest of all primary elements and has the most rapid response time for the range desired: $0^{\circ}F$ to $120^{\circ}F$. It also has high sensitivity, but its low voltage output requires a superior metering system which can measure in the microvolt range. Since this requirement involves expensive equipment and since the thermocouple circuit may be vulnerable to ambient temperature changes due to junctions and solder joints, thus producing extraneous voltage, the use of the thermocouple as a transducer was bypassed.

The resistance thermometer is superior to the thermocouple in accuracy and compatability to the recording device. The Wheatstone Bridge with various modifications can be used as a method of measurement so that expensive accessory equipment is avoided when using a resistance thermometer. The only limitation in using this transducer is the slower response time and current levels which must be kept small in order to omit any heating of the element. Based on these considerations, a Beckman Thermo-Compensator Model No. 19580 was adopted as the temperature transducer. This system is described further in Section II.

II. TRANSDUCERS IN USE

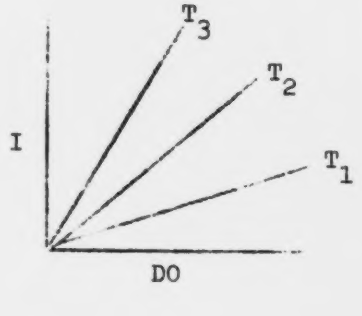
A. Dissolved Oxygen

The electrode which has been used for measurement of dissolved oxygen is the Beckman Model No. 76365 Polarographic Oxygen Sensor. This is a membrane type electrode with gold cathode and silver-silver chloride anode. The polarographic cell utilizes an externally applied voltage to obtain the necessary potential at the cathode to achieve an oxygen limited current.

The anode of this sensor is electrically connected to the cathode by a layer of potassium chloride gel and the entire cathode-anode assembly is separated from the sample by a Teflon membrane which is gas permeable. Oxygen diffused through the membrane is electrically reduced at the cathode by an externally applied voltage of 0.8 volt. A typical plateau curve is shown in Figure 6. The resulting current which flows between the anode and cathode is proportional to the partial pressure of oxygen in the sample. Since the current-voltage curves shift somewhat with age, periodic checks should be made for the correct applied voltage to be used.

The membrane-type electrode used here is flow-sensitive and consequently requires that a minimum flow rate of approximately 1-1/2 ft/sec be available in order to obtain consistent results. This flow is not applied continuously in order to conserve power; however, the electrode does have an equilibrium time following the application of flow across the membrane and, therefore, it is necessary to start the flow system at some time previous to the measurement. In the system being used here, flow rate is initiated at the beginning of the measurement sequence for all parameters and the dissolved oxygen measurement is made last in the sequence, thus allowing from two to three minutes of flow previous to measurement in order to reach equilibrium.

The electrodes are calibrated by comparing the current obtained at a specific point on the polarographic curve with Winkler measurements (Appendix I) made at a series of temperatures which cover the desired temperature span. An important characteristic of these electrodes is that they are sensitive to changes in temperature. This temperature sensitivity is illustrated graphically as follows: If the output current (I in microamps) for the given electrode is indicated on the y-axis and the dissolved oxygen (DO in parts per million) is indicated on the x-axis at three different temperatures (T_1, T_2, T_3), the plot shown below would result:



This plot shows that the slope, or ΔI/ΔDO, is the variable due to a change in temperature (ΔT). Using this information, a curve known as the Ø-curve is made for the electrode in use at a particular temperature. The procedure is as follows: the output current (I) at a particular temperature is divided by the DO in ppm to yield the slope or sensitivity (referred to as Ø) for that temperature. Several Ø's are obtained at different temperatures and then plotted on semi-log paper with Ø indicated on the log-scale and temperature on the common scale. To determine the oxygen content of an unknown solution then, one need know only the output current and the temperature, since from the Ø-curve (Figure 2) for the known temperature, one reads Ø, then by applying the relationship:

(Output Current)/(Ø) = DO,

the dissolved oxygen concentration in ppm of the unknown sample may be calculated.

Of course, the above calibration method is valid only when the residual current is so small that it can be ignored. The residual current is checked by placing the electrode in an oxygen free solution. (A solution is made oxygen free by bubbling nitrogen into it for a few minutes; it is also advisable to add a small amount of sodium sulfite to help remove the oxygen.) Procedures for attempting a reduction of residual currents are given in Appendix II. Decay of output current requires that the electrode be recharged after a period of time.

It is possible to rejuvenate the Beckman 76365 or 39065 O_2 electrodes; the method for doing this is described in Appendix II.

In view of the problems associated with short lifetime for the above electrodes, reference is made to better electrodes which are described in Section I of this report.

B. pH

The stability of the system over a long period of time is of primary concern in choosing an electrode assembly for measuring pH. Since the system design calls for several weeks of unattended activity, it is essential that the electrodes, reference and glass, be stable under various temperature and flow conditions which occur naturally, as well as being unaffected by thick accumulations of algae and slime which will likely occur in a submerged system. The Beckman Glass Electrode No. 19500 with silver-silver chloride internals and the Beckman Reference Electrode No. 19550 (palladium annulus junction, silver-silver chloride internals) were tested under controlled conditions and in a natural stream and were found to be satisfactory for long term immersion. The electrode system is enclosed within a Beckman Process Submersion Assembly to insure protection. The reference electrode is a type which must be externally pressurized; about 10 psi air has been used with this electrode. The electrode will clog if allowed to stand unpressurized in water with considerable algae growth.

As used in the monitoring system, the pH electrode measurement is performed in terms of millivolts and conversion to actual pH is made later by considering correction required for the water temperature at the time of measurement. The asymmetry potential must be known in order to completely characterize the pH measurement system. The calibration (Figure 7) of the electrode system is accomplished by measuring the emf in millivolts at various pH values with the Beckmen Expanded Scale pH Meter (Model 76). Buffer solutions are used to effect the calibration.

Preceeding field installation, careful measurement is made at constant temperature of the millivolt output of the pH electrode and reference electrode potential for at least three different pH values. From a plot of these measurements, the value of the asymmetry potential may be taken as the difference at pH 7 between the value indicated by the plot and 0.0 millivolts (Figure 7).

Care must be taken in designing a pH meter system because of the characteristics of the signal source. The voltage developed across the glass electrode bulb from hydrogen ion activity appears to be hidden behind the resistance of the membrane. This resistance for the Beckman No. 19500 electrode is approximately 10 to 20 megohms. Actually, a voltage divider is formed by the input impedance of the pH meter and the membrane resistance. The input impedance of the meter should be much greater than the membrane impedance to keep the signal loss low. For example, if the membrane impedance were 10^7 ohms, an input impedance of 10^9 ohms would lead to a 1 percent signal loss. The input impedance of the system used to measure the pH electrode voltage in the system under discussion is a minimum of 100 megohms when off balance, and, depending upon the degree of balance obtained, theoretically approaches infinity at the balance point. The metering system is calibrated to read ±300 mV for full scale deflection. The pH readout is accomplished, as for all parameters, by a servomechanism and punched tape.

If the Beckman Process Glass Electrode tip should become coated by adhering solids from a stream, this barrier could interfere with pH measurements and the electrode would require cleaning with a suitable solvent. Surface deterioration of the electrode tip is indicated by several factors: (1) a lag in response time; (2) failure to check against two buffers; (3) indication by pH meter readings that the standardization range is insufficient; and (4) sensitivity of pH meter needle to physical movement of the electrode. Rejuvenation of the electrode is required if any of the above factors are observed. The rejuvenation process involves immersing the bulb of the electrode in 0.1 N hydrochloric acid or alternately immersing the bulb, momentarily, in acid and alkali. If these procedures fail, immerse the electrode tip in 20 percent ammonium bifluoride solution for three minutes, or in 10 percent hydrofluoric acid for 15 seconds. After this process, rinse the electrode in flowing tap water, dip it briefly in 5 N hydrochloric acid to remove fluorides, then rinse again in tap water (23). Rejuvenated electrodes may be stored in 0.1 N hydrochloric acid but the solution must be rinsed off with water before using the electrode.

The reference electrode used in this system is the Beckman 19550 Process Reservoir Reference Electrode (palladium annulus junction) silver-silver chloride saturated with silver chloride electrolyte. The reference electrode is pressurized to maintain a differential pressure between the reservoir and the sampled stream to assure flow of the electrolyte through the junction to maintain electrical contact with the solution. About 10 psi air is applied to assure flow of the electrolyte through the junction, but this may be increased if deeper immersion is expected. The differential positive pressure may be from 2 to 20 psi with 5 psi as optimum.

Drifting of the pH meter may indicate a clogged junction. If this occurs, the electrode tip should be boiled in water or, if necessary, in a potassium chloride solution to remove any foreign material. If, however, the foreign material can be identified, a proper solvent may be used to clear the junction. The electrode should be replaced if the junction is not cleared by this procedure (24).

A questionable electrode may be referenced to a similar accurate reference electrode. The voltage difference should be measured while both electrodes are in a potassium chloride solution and also a buffer solution. The voltage difference should be within ±5.0 mV of zero. If the voltage is the same in both solutions but not zero, the internal element is faulty or the electrolyte is contaminated. The electrode should be replaced if the voltage output is not corrected by rinsing and refilling the electrode with fresh electrolyte. If the voltage is different in both solutions, the junction is clogged and must be cleared as previously discussed.

C. Conductivity

The transducer used to measure conductivity is an Industrial Instruments, Inc. dip-type conductivity cell Model CEL-VK, platinized platinum unit. The cell constant should be chosen with regard to the conductivity of the water at the site being measured. Provisions are made in the measurement bridge to shift the range of measurement by a factor of ten in either direction from that normally measured by a given cell constant. The conductivity of the solution is determined indirectly by measuring the resistance and determining the specific conductance from the relationship:

$$L_s = K/R$$

where L_s is the specific conductance in mhos/cm^3, K is the cell constant, and R is the resistance of the cell in ohms. Since conductivity cells are not ordinarily available with a highly accurate value of cell constant, it is necessary to measure the cell constant using standard solutions such as potassium chloride. Solutions of potassium chloride are prepared according to directions in the Handbook of Chemistry and Physics (25). The resistance of the cell is measured using these standard solutions, and the actual cell constant can be determined by applying the above equation. An AC bridge should be used to measure the cell resistance in order to prevent polarization. If it is suspected that the conductivity cell is giving incorrect measurements, it may be necessary to replatinize the electrodes. One method for doing this may be found in Experimental Physical Chemistry (26). (Platinizing kits may be purchased from the manufacturer of the cell if material is not available locally.) When calibrating the bridge used to measure conductivity, it may be convenient to use a decade resistance box instead of the conductivity cell itself. It is necessary to have some knowledge of the resistance (specific conductance) which will be found in the area where measurements are to be made. The following are some typical values at 25°C for measurements made locally using an electrode with a cell constant of 0.091.

Liquid	R (Resistance)	L_s (Specific Conductance)
Distilled H_2O	33.60 K	2.71×10^{-6} mhos/cm^3
Tap H_2O	1.78 K	51.00×10^{-6} mhos/cm^3
Lake Maumelle H_2O	3.25 K	28.00×10^{-6} mhos/cm^3
Arkansas River H_2O	0.09 K	1000.00×10^{-6} mhos/cm^3

D. Temperature

A resistance thermometer with an element made of Driver Harris Hytempco (a nickel alloy) is used for temperature measurement. The transducer used is a Beckman Thermo-Compensator (Model No. 19580). The resistance of this element is 4196 ohms at 25°C changing by 14.47 ohms/°C. One of the reasons for using this unit as the temperature measuring probe was that it fit an already available sealed hole in the head being used for pH measurement, thus eliminating the necessity for building a separate bracket and support assembly for the resistance probe. The tolerance of the thermal element is good enough that one may use a decade resistance box to substitute for the probe when calibrating the bridge for measurement of temperature. It is necessary that a precision decade box be used for this calibration since the temperature measurement must be made to a high degree of precision because the reading obtained is used to correct other transducers for temperature sensitivity. The time constant of the resistance thermometer is approximately four minutes. If measurements are made on the resistance probe, care must be taken to keep applied voltage low in order to reduce self-heating. Self-heating of the probe will cause a shift of the temperature of the resistance element and, consequently, an indicated change in resistance even if the thermal element is in a temperature controlled bath.

E. Chloride

The measurement of chloride resembles that of pH. The output of the chloride electrode is measured in millivolts by the parameter board and system. Provisions are made for the board shown in Figure 39 to measure voltages from 0 to 300 millivolts. This voltage value then, together with the temperature value, is used to obtain the value for chloride from a plot of the particular electrode which has been made in the laboratory.

F. Redox

The measurement of redox is another measurement similar to that of pH. Provisions are made for a zero adjustment and an adjustable span of voltage across the servo potentiometer. The voltage of the electrode system is measured and, from laboratory calibration, data values for the redox calibration are obtained.

III. SYSTEM POWER REQUIREMENTS

The discussion of system power requirements is divided into several cases. The first case to be considered is the requirements imposed by the initial system which was constructed. A combination of circumstances, including a choice of servo systems which was made on the basis of price and at a time in the past when suitable low-cost servo motors and amplifiers were not available, required 115 volts AC for its operation. Second, and perhaps most important, the dissolved oxygen measurement required considerable flow rate across the face of the electrode, and dependable provisions for this flow rate required considerable power. Third, the early choice of a square-wave DC-AC converter proved unsatisfactory for use in bridge measurements, necessitating the use of a less efficient sine-wave DC-AC converter. The increased power requirements resulting from the above circumstances led to a total system power requirement of the following:

The system drain of the completed system requires 8 amperes at 12 volts for 2-1/2 minutes of each 15 minute period, or 96 watts for 1/6 of the time leading to a 16-watt continuous demand. If it is assumed that some continuous generating method is available and that storage in storage batteries is required; then, assuming a 70 percent efficiency recovery from the battery system, 23 watts continuous power availability would be required. At an earlier stage in the project it appeared that thermoelectric generators would fulfill the requirements, and considerable effort was expended in testing thermoelectric generators having an output of 8 watts. At that time, other portions of the system had not been completed and it was anticipated that a 5-watt continuous supply would be sufficient. It is probable that methods could have been found to keep the power requirements down to this 5-watt continuous figure if the thermoelectric generators had proved satisfactory. However, as is illustrated by the curve in Figure 8, the decay of the thermoelectric generator output, which is typical of three different units which were tested, together with their inital cost, which was approximately $1100.00, led to the conclusion that, for our purposes and at the time a decision had to be made, a motor generator set would be required to supply the power needed. Once this decision had been made, it was evident that the smallest motor generator set available, which had automatic restarting facilities incorporated in it, would easily supply considerably more power than it had been intended to use. Consequently, this led to relaxation of system power conservation and accounts for the rather high figure of power which is used by the present unit.

A second estimate of power requirements of a system based on the present approach, and using the same recording system which leads to a rather slow recording time and consequently a high overall power demand, would consume or require something on the order of a 5-watt continuous supply. Changes would be necessary in the servo system in terms of adopting a DC motor and DC amplifier as well as incorporation of a sine-wave supply of low power consumption for use only on the AC bridges. If this approach is followed without appreciable further changes in the overall system, considering conversion losses of a storage battery system, one would require a 5-watt continuous supply.

Further consideration of the system involved and the requirements imposed by it led to the conclusion that it would be possible at the present time and with presently available electronic components, particularly integrated circuits, to build a system which would operate on much less power than the figures quoted above. The electronic components which would make possible such a system have become available at prices allowing their consideration only in the last 18 months. The key to any such system is the inclusion of some method of recording which consumes minimum power. Appendix III describes a photographic method of recording which would consume little power. This is one possible approach; however, it would require construction of a unique piece of hardware for use in a system such as this, as well as involving the construction of translation equipment to remove the data from the photographic film at the collection agency. A second possibility, which is currently under examination by this laboratory, is a method of using a magnetic tape recorder to record the information. Present indications are that such a system is entirely feasible at reasonable cost, and that if such a system were to be constructed, it would be entirely possible to operate it from either primary cells or from storage batteries of various kinds. As an example, preliminary calculations indicate that such a system could operate from a set of rechargeable alkaline storage cells. Requirements indicate that 4 such batteries would be needed at an approximate cost of $50.00 and that a single charge should operate a system designed for minimum power consumption for a period of up to one month. This minimum power operation can be accomplished only if a method, such as that described in another portion of this report, is used for measuring dissolved oxygen where no flow requirement is placed upon the oxygen measurement. Consideration of a minimum power system is probably futile if a flow rate requiring method of oxygen measurement is used.

With regard to thermoelectric generators, the manufacturers presently state that the decay rate of the generator should approximate only 5 to 10 percent a year; however, no guarantee extending beyond one year could be obtained. Consequently, there is no concrete way to determine exactly what the cost of power generated by a thermoelectric generator system would be over a period of several years. Also, our experience with engine generators, whose cost is compatible with the aims of the system design, indicated that one would experience considerable trouble maintaining this equipment in the field. All of the above evidence indicates that emphasis in the future for a system of the type described in this report should be on the minimum power type system with operation depending upon batteries.

IV. PACKAGING REQUIREMENTS

For the monitor, as it was constructed, no stringent attempts were made to reduce the size of the electronic package and recording system except to provide that they be contained within a 30 gallon drum which was sealed to prevent entry of moisture. The unit was mounted in the boat such that it was possible for one man to board the craft either fore or aft in order to service the equipment. The boat was large enough and stable enough to allow one to stand in either well of the boat. A gas tank was mounted across the back of the boat containing sufficient fuel to operate the motor generator set for a period of approximately 2 months.

In the earlier stages of the project when it had been hoped that battery powered operation would be possible, it had been visualized that something resembling an oil drum would be used in the form of a buoy to contain the instrument. However, upon reflection it is evident that any structure with a depth of something resembling an oil drum would present considerable difficulty if repairs were necessary to the equipment contained in the lower section of the drum. In the case originally planned, the batteries, probably lead acid storage batteries, would have been placed in the bottom of the drum. A construction of this type would then have made desirable the isolation of the battery compartment from the rest of the electronic section because of the possibility of sulfuric acid fume damage. Also, a structure the size of the drum would be unwieldy to handle and difficult to pull on board a boat unless a large boat with some sort of crane facility was available. If it proves possible to reduce the size of the instrument at some future date, and to operate from smaller batteries than originally had been planned, then some container smaller than a drum might prove satisfactory. The container used should be of a size and weight which would allow one to lift it on board a boat using only hand labor.

V. MONITORING SYSTEM

A. Recorder

The recorder used in the monitoring system is a Fischer and Porter Analog-to-Digital Recorder, Series 1542 (Figure 9). This recorder was chosen because its price was reasonable; translators were available commercially for translating the information from the recorder to punched cards or other formats; and it offered an accessible visible readout of the information which had just been recorded. From the standpoint of direct compatibility with computer data handling, it would have been more convenient to have used a magnetic tape recorder. However, tape recorders, recording in a format which may be directly handled by the digital computer, cost approximately $3,000; and, in addition, would have required some visible readout device in the monitor for testing and checking purposes.

The recorder which was adopted has its information available in binary coded decimal form with a resolution of one part in ten thousand. The information is recorded on punched paper tape which may be obtained with foil backing to facilitate reading with photoelectric devices. The recorder itself does not contain a drive mechanism for the code wheels which produce the binary coded decimal format. A punch motor and control switching system are included in the original recorder (Figure 10). One of the changes made on the original recorder was to add a 115-volt AC motor and geared belt drive for the punch mechanism in order to allow the punch cycle to be completed faster so that more time was allowed during the measurement cycle. It has since been concluded that the original drive as installed probably would have been satisfactory, and the time gained versus the complexity of the change probably was not justified. The original punch system operates from a 7-1/2 volt DC supply and requires 200 milliamperes. This power requirement could easily have been provided from the system involved.

The data tape for this recorder is approximately 400 feet long and allows 120 punch-outs per foot. If one assumes the recording of six parameters at 15 minute intervals, then a roll of tape is sufficient for 83 days of recording. Since tape is usually removed at more frequent intervals, a more practical figure is probably two months of recording per roll.

It is necessary to rotate the input shaft of the recorder 100 times for travel from one end of the scale to the other. Each rotation is equivilent to 100 counts of the binary-coded-decimal scale. In the original timing sequence as planned, 20 seconds of a complete 30 second parameter interval were allowed for the recorder traverse time. If one assumes that the recorder is required to travel full scale in 20 seconds, then the drive system must rotate at a rate of 330 rpm. Starting torque requirements were approximately 1 inch-ounce. Running torque was considerably less; consequently, a motor with a no-load speed of approximately 330 rpm and a starting torque of 10 inch-ounces was considered to be suitable for driving the code wheels. The motor chosen was a Minneapolis-Honeywell Reversible Induction Motor, Catalogue No. 365754-9. This motor has a requirement of 11 watts for the line phase and approximately 0.5 watt for the control phase, allowing the servo-amplifier to operate at reduced power output compared to motors where the line phase and control phase are equally split.

Since it was desired to use a 10-turn potentiometer for the potentiometric feedback circuit arrangement, it was necessary to add a gear box with a 10-turn reduction between the motor-recorder shaft and the input to the potentiometer. Since considerable power was available and the inertia of the code wheels was rather high, it was also necessary to add a clutch in order to prevent the possible overrun and destruction of the internal wiper arm assembly of the potentiometer. In addition, a mechanical stop arrangement was incorporated which stops the complete system one-half turn from either end of the 10-turn potentiometer (Figure 10b).

Two translators for the tape used on the recorder are available. One translator has various options, but essentially it is automatic and translates the tape directly to control of an IBM 026 Card Punch, or into other optional computer input forms. Cost of this translator is on the order of $6,500.

A second translator is available which translates the punched-hole tape into a Nixie readout, from which a typist or a card-punch operator can read the value. The conversion is from binary coded decimal (BCD) directly to decimal form. Because of delivery difficulties encountered in obtaining one of the visual readout translators, this laboratory constructed its own translator by modifying a high-speed paper tape reader of the eight-level Friden type to take the sixteen-level Fischer and Porter tape. This tape then was read directly into the computer without any intermediate steps and stored in memory, after which it was further translated as described in Section VIII of this report.

B. Motor Generator

The decision to build a self-contained system that would operate unattended for a month at a time required one of two approaches for the provision of electrical power. The system had to be capable of operating from a stored supply of energy or it had to generate its own electrical power. The latter alternative was chosen since it would allow more design possibilities. A motor generator unit was selected in preference to thermoelectric generators or solar conversion sources for reasons described in Section III. The unit is capable of producing 500 watts of electrical power at 12 volts. It has a sensing circuit which allows automatic charging of a standard 12 volt lead acid automotive type battery. The start and stop voltages may be manually adjusted for optimum charging and discharging performance. When the battery voltage reaches a preset minimum value, the sensing circuit closes the cranking relay which applies current to the exciter coil in the generator and cranks the gasoline engine. When the required engine speed is reached, the back emf in the generator becomes sufficient to open the cranking circuit and close the reverse current relay, thereby applying charging current to the battery. When battery voltage reaches its preset upper limit, the sensing circuit grounds the engine magneto and stops the engine.

The motor generator unit was modified extensively to meet various environmental and electrical requirements. The sensing circuit and part of the controller unit were physically removed from the original mount on the motor generator and repositioned in the forward well to permit operation from the same area as the electronic controls of the instrumentation module. This location also removed these elements from much of the vibration and heat generated by the gasoline engine.

The electronics package, the stirring motor, and the DC to AC inverter operate from the 12 volt DC line supplied by a storage battery. In order to obtain optimum use of the charge stored in the battery, it is desirable to allow the equipment to drain the battery to a voltage of 2 volts per cell or less. If one then attempts to start the motor generator set, the large drain of the starting winding tends to drastically drop the voltage of the storage battery. Consequently, it was found desirable to separate the function of charge storage for equipment usage and charge storage for starting purposes. This separation was accomplished by allowing the start battery to be charged in parallel with the equipment battery, which has been referred to as the run battery. The start battery is separated from the run battery by a heavy diode. Consequently, the run battery charges first and the start battery is charged at a slightly lower voltage than the run battery. When the equipment is in use, the diode separates the run battery from the start battery and prevents the start battery from being charged. Consequently, when the start command is initiated, a freshly discharged battery is available to start the generator set. This mode of operation considerably increases the reliability of starting for the motor generator set.

If the motor does not start on command, a thermal protection circuit, relay R1 and zener diode D2, disconnects the start battery from the motor generator set in order to prevent overheating of the start winding and to protect the start battery. When this happens, the equipment continues to run and operate from the run battery. Below approximately 10 volts, the equipment does not operate reliably and one also risks the possibility of vibrator contact damage in the DC to AC converter. Therefore, a dropout circuit was installed so that when the run battery discharges below 10 volts, all equipment is disconnected from that battery. This particular relay requires manual closure after it has opened because of low battery voltage.

Since considerable trouble was experienced with the thermal relay, it was replaced with a time delay relay R2, relay R3, and switch S1 (Figure 10C). The operation of this protection circuit is as follows: the closure of push button switch S1 supplies current to the coil of R3 through the normally closed contacts of R2 and closes the contacts of R3. S1 is released and has no further function. If the cranking current is required for longer than 30 seconds, the time delay relay R2 opens the circuit to the coil of R3, thus causing the contacts of R3 to open, disconnecting the sensing circuit from the system and stopping the cranking process. Reset is accomplished by the momentary closure of switch S1.

The original choke mechanism of the gasoline engine was mounted in direct contact with the exhaust system. It is an electro-mechanical device which apparently has some thermal properties which decrease the choking action if the engine is hot. The choke is energized by the choke solenoid (Figure 10C) which has power applied to it only during the starting period. Several choke mechanisms were damaged due to excessive heating and did not provide satisfactory operation. In this application, the engine started infrequently (about every 12 hours) which allowed the replacement of the choke solenoid with a solenoid physically removed from the exhaust system and connected to the butterfly valve by a longer shaft.

The original fuel tank in the motor generator unit was a small (approximately 1/2 gallon) gravity feed type. It was replaced with a 20 gallon tank mounted at the rear of the rear well. An electric fuel pump and filter assembly were installed to provide a positive supply of fuel to the engine.

Numerous minor problems plagued the motor generator set throughout the contract period. It is estimated that approximately 75% of the down time of the system could be attributed to the motor generator.

C. Clock

The primary timing device used to control the basic timing sequence of the monitor is a battery powered sequence timer made by Geodyne Corporation. The clock is a chronometric 15-jewel, temperature compensated movement which operates a single-pole, double-throw switch. Cams are available with one, two, three, four, or six lobes enabling the switch to be operated every 60, 30, 20, 15, or 10 minutes. The basic cam revolution used was one per hour. The power input for the clock is 4-1/2 volts DC. In the monitoring system, the Geodyne clock is operated through a 22 ohm dropping resistor from the 12.6-volt line (Figure 11). The chronometric accuracy of the clock is stated by the manufacturer to be ±10 seconds per day over a temperature range of 30°F to 140°F. The timing accuracy was checked in this laboratory and was found to be within the manufacturer's specifications. The total maximum error based on an elapsed time of 50 days would be 8 minutes and 20 seconds. It was felt that no ambiguity would exist in timing since this time is less than one of the fifteen minute cycles and since the monitoring system requires attention at intervals more frequent than the 50-day quoted period. The timer has been operated for a period of six years without encountering any problems.

D. Programmer Timing

Programmer timing employs an A. W. Hayden Cam Actuated Sequence Timer (Figure 11). The timer has nine timing channels available and is driven by a 6-volt motor which is supplied from a zener regulated source.

When the Geodyne Clock switch closes, it maintains contact long enough for one of the cam-actuated contacts to perform a holding function to maintain rotation of the programmer motor. The clock switch must be closed for a period long enough to allow the hold function to take over and short enough such that it does not re-initiate the hold sequence at the end of the programmer cycle. Since the total programmer cycle was set to be either 2-1/2 or 3 minutes, depending upon the number of channels being used, the clock closure duration was set at 80 seconds with the adjustment available on the Geodyne Clock. The hold switch, besides maintaining voltage on the programmer motor, supplies 12 volts to the various relays and other 12-volt requirements of the monitor and also operates a relay which activates the DC to AC sine wave 115-volt 60 cycle converter. Available cams were used to control each of the measurement relays as they are required in sequence; however, a special cam was cut for the punch function, since it is required to operate the punch switch for the number of measurements which are being made during one programmer cycle. Consequently, if five measurements are being made, a five-lobe cam is required; and if six measurements are required, a six-lobe cam must be inserted (Figure 12).

The programmer cycle is divided into thirty-second intervals for each parameter. Of this time, 20 seconds are allowed for servo rebalancing to allow the position of the code wheels to change from that of the previous value. The servo system motor rotational speed was made such that full scale change should be achieved in less than 20 seconds.

Of the remaining 10 seconds, approximately 7 seconds are allowed for the punch cycle and 3 seconds for the switching in preparation for the next parameter. The actual punch function itself takes place approximately 4 seconds into the 7 second period. This timing function (Figure 13) is achieved by the adjustment of a series of cams; therefore, the above times are approximate.

E. Transducer Switching

Since one common amplifier and servo amplifier are used to record all functions, it is necessary to perform a switching function to measure the different parameters involved (Figure 41). When the programmer closes the cam-operated switch for a particular transducer, an IBM wire contact relay is energized (Figure 14). This relay applies power to the transducer board which has been selected (Figure 15) and it also connects the servo potentiometer to that board. At the same time, connections are made to jumpers installed on each of the boards which determine what kind of measurement is being made (Figure 16). Facilities are provided to make DC measurements from a high impedance source, DC measurements from a low impedance source, and measurements where the DC preamplifier is removed from the circuit and an AC signal generated on boards is fed directly to the amplifier system (Figure 17). When a board is wired for a particular function, jumpers are placed on that board to determine what kind of measurement the amplifier system will make for that parameter. The jumpers are then switched into the circuit when the IBM relay contacts close for that particular parameter. A 12.6 volt DC line is available to the board at all times for use with those functions where the voltage must not be removed from the transducer at any time (Figure 18).

F. Amplifier

For all DC measurements, the signal is amplified by an electrometer input stage which is preceeded by a highly insulated chopper intended for this type of service (Figure 19). A 100 megohm resistor preceeds the input to the chopper to prevent loading of the electrochemical transducers when an electrode is suddenly switched into the amplifier. It is not sufficient to achieve high input impedance only at balance, which would be true of most potentiometric systems. In this application, the amplifier is being switched from one electrode to another in relatively rapid sequence. If the input impedance to the amplifier were low when the potentiometric measurement was away from the balance point, it could introduce a shift in the potential produced by some of the transducers. Consequently, it is necessary that the amplifier have high input impedance at all times regardless of whether or not a null balance has been reached.

Small capacitors are inserted following the high resistances into the amplifier in both the signal input lead and the reference input lead; these capacitors reduce the effect of stray pick-up and transient noise. The signal is coupled following the chopper through a capacitor with high leakage resistance into the input of an electrometer. The electrometer in this unit is a CK 5886 tube followed by transistor stages. At the present time, field effect transistors would be fully as effective as the tube which was used. The electrometer tube is followed by a one-stage silicon transistor amplifier which in turn drives an emitter-follower for impedance transformation into the transformer which is located on the second amplifier board. The same electrometer amplifier is used for both high impedance and low impedance measurements. The difference is that a direct connection between the cable coming from the transducer through highly insulated contacts and the reed relay is available for high impedance measurements, such as pH. For low impedance DC measurements, the signal is coupled from the board through a separate reed relay and into the input of the electrometer amplifier (Figure 16).

The second amplifier board, designated as Servo Amplifier Board Number 1 (Figure 20), consists of a transformer, relay and operational amplifier (Figure 21). The transformer is used to isolate the electrometer input amplifier circuit from the remainder of the servo amplifier. This allows floating measurements to be made by the electrometer input amplifier. The operational amplifier on Servo Amplifier Board Number 1 is connected as a non-inverting amplifier with gain. It also has diodes across both input and output. These diodes serve the dual purpose of limiting the output signal in the case of serious overdriving in order to reduce blocking time and protecting the operational amplifier from extraneous signals which might cause damage to the operational amplifier. The gain of the amplifier is set by the ratio of resistor RB to resitor RA and is roughly 300. The second operational amplifier on Servo Amplifier Board Number 2 is connected in similar fashion, except that a larger number of diodes are connected across the output in order to allow a larger voltage swing for following stages (Figure 22). Once again these diodes serve to speed up the recovery time from serious overloads. This amplifier is also connected as a non-inverting amplifier with gain and has a gain of approximately 350. It is followed on this same board by a Darlington Emitter Follower output stage which drives the following board where gain adjustments are available for each channel (Figure 23). All of the potentiometers are driven in parallel on Servo Amplifier Board Number 3, from which the signal is coupled by another Darlington Emitter Follower into the following board. The gain adjustments on Servo Amplifier Board Number 3 are set in conjunction with each individual transducer to optimize response time and minimize overshoot.

The servo amplifier on the final board has a gain stage followed by a phase splitter which in turn drives Darlington-connected transistors feeding a push-pull output stage (Figure 24). Feedback is applied around this stage to fix the gain in spite of temperature variations. The power supply feeding the final push-pull amplifier stage is full-wave rectified to increase efficiency and reduce heating of the output transistors (Figure 25). The servo power amplifier is also temperature compensated by a thermistor to prevent thermal run-away at high ambient temperatures. All transistors and amplifiers are silicon units and are being operated conservatively. No trouble has ever been experienced with loss of transistors because of overheating.

Because of decisions made in the early stages of construction of the monitor, the servo amplifier and motor system are not as efficient as would be possible with equipment which is presently available at reasonable price. It would be more efficient to use a DC Servo Amplifier and DC Servo Motor for driving the recorder if the unit were being designed at the present time. This would also facilitate the application of tachometer feedback to reduce overshoot. Since the inertia of the code wheels is quite large, there is some problem in setting the gain of the amplifier of the present system in order to minimize overshoot and retain response time. In the early stages of the development, it was not felt that the complexity of a tachometer feedback system involving an AC servo motor was justified, and performance has been satisfactory with the present system.

G. Circuit Boards

1. Dissolved Oxygen

The requirements for the dissolved oxygen circuit board are that it furnish a stable source of polarizing voltage for the electrode and make provisions for measurement of a relatively low current. The polarizing voltage is obtained from a supply which is regulated by a zener diode. A voltage divider is placed across the zener diode and provisions are made for an adjustable polarizing voltage. The voltage range available with the value shown on Figure 26 is from 0.75 volts to 0.95 volts. The electrode current is determined by measuring the voltage drop produced across a 50,000 ohm resistor by the electrode current flow. The voltage which represents the dissolved oxygen current is available at the terminal marked H and 3 on Figure 26. This voltage is then compared with the voltage across the servo potentiometer. The servo system drives until no voltage difference is seen between the sliding arm of the servo potentiometer and point H. The number of divisions read out on the recorder punched tape then represents the percentage of the total voltage across the potentiometer. This voltage is determined by the zener diode voltage and the 42.2K resistor which is placed in series with the potentiometer. This voltage was 0.152 volt for the values and the potentiometer in the circuit which was used. If one divides this value of 0.152 volt by the 50,000 ohm resistor which is used for current measurement purposes, the value of 3.04 microamps, full-scale, is found for the full-scale reading of the potentiometer. This value is later translated from recorder divisions back to current and, with the aid of the Ø-curve (described in Section II) and the temperature of the water, one obtains the value for dissolved oxygen. This translation is done automatically by the computer program; however, for field use it is necessary to have available the Ø-curve for the particular electrode in use, if one desires, for example, to compare the field reading with a Winkler test taken in the field. Figures 26 and 27 both give the same information; however, Figure 26 more clearly illustrates the operation of the measurement, whereas Figure 27 more clearly designates the connection of the circuit board itself to the main portion of the measurement system. Terminal connections to the transducer leads are shown in Figure 28.

2. pH

The circuit used on the board for measurement of pH is shown in Figures 29, 30, 31, and 32. The measurement of pH is a voltage measurement with both positive and negative values being possible. Since the output of the pH probe is approximately 59 millivolts per pH unit at standard conditions, the pH range may be determined by arranging the span of voltage placed across the servo potentiometer. The range of pH was chosen to be from 2 to 12, or ±5 pH units about the neutral value of 7. With reference to Figure 29, the adjustment labeled "Zero" on the diagram corresponds to the asymmetry potential adjustment ordinarily available for pH measurement. One may use this adjustment to balance out the asymmetry potential of the electrode, or, as an alternative, short-circuit the connections labeled "TB-2" and "[illegible]", which is the slider of the servo potentiometer, and adjust the zero adjustment for exact mid-scale reading. In this case, 5,000 divisions on the recorder will then represent zero millivolts. The output of the pH probe, in this case, will then be measured as the sum of the asymmetry potential and the pH voltage as given by the Nernst equation. Approximately ±50 millivolts adjustment range is available for asymmetry voltage. This probably should be increased slightly since values of asymmetry potential of between 50 and 60 millivolts have been observed with several of our electrodes. The value shown for the servo potentiometer voltage dividing string allows a span of ±300 millivolts, which in turn allows the measurement of roughly ±5 pH units. Because of persistent problems with stray signals occurring in ground loops, a special supply is made available for the pH measurement and is also available for any other measurements which have the same requirements as pH, such as chlorides and redox. This supply consists of a series of small nickel cadmium cells which are placed on charge during the period of time when no measurements are being made, and which are switched to the parameter boards and made available during the measurement period to provide a floating supply for the board. Better shielding in certain of the transformers in the system probably would have eliminated the problems which were encountered; however, the battery supply was chosen in the interests of facilitating the measurement to be made with the system involved. If a considerable number of measurements, all requiring power from this nickel cadmium supply, are installed simultaneously, it would be necessary to change the 180 ohm resistor to some lower value to maintain the nickel cadmium batteries at full charge.

The measurement of pH and other parameters of similar nature is a very high impedance type measurement; all grounds and shields must be carefully connected, and provisions must be made to keep the insulation resistance of all the wires connected to the electrode at the highest possible value. This requires a drying agent in the head which contains the electrodes, and also requires that the area of the measuring circuitry where these electrodes are connected be kept clean and dry.

3. Conductivity

The conductivity board makes provisions for measuring conductivity in an AC Wheatstone Bridge. The conductivity parameter circuit is shown in Figures 33, 34 and 35, and reference may also be made to Figure 36 for temperature which, except for bridge values, is made in the same manner. Sixty-cycle AC from the DC-AC converter is used for the bridge, since it is necessary that this AC voltage be in phase with the servo motor reference winding. One-half volt AC is applied to the bridge, and 250 millivolts are applied to the servo potentiometer and the conductivity cell. This voltage changes somewhat with loading for high values of conductivity which in turn require relatively low resistance on the part of the servo potentiometer to obtain balance. The servo potentiometer is used in this case as a variable resistor, and the bridge is arranged so that the servo potentiometer drives to produce null-balance signal between terminals K and H. Any unbalance between these two points is sensed by the amplifier and applied to the servo motor in the correct phase to drive the servo potentiometer to zero voltage. The bridge, as arranged, presents the reading from the conductivity cell as a resistance which may be read directly from the recorder.

This also simplifies calibration, since one may use a resistive decade box to set and check the conductivity parameter board by using the resistance box to replace the conductivity cell.

4. Temperature

Temperature is measured in a null-balance Wheatstone Bridge, with the servo potentiometer off-set in one leg of the bridge by a resistor which compensates for the 0°C resistance of the resistance thermometer used (Figures 36, 37 and 38). This allows the expansion of the temperature range of interest to occupy full-scale on the recorder. The bridge itself operates as a simple Wheatstone Bridge measuring resistance. Precautions which must be observed are to keep the applied voltage to the thermocompensator at a relatively low value to prevent self-heating. The tolerance on the thermocompensator used for a temperature measuring element is such that little adjustment should be required. In order to reduce the number of adjustments on the board and to reduce the likelihood of change of calibration, it has been our policy to adjust the bridge using a decade box to set in a resistance value representing some value of resistance at the lower end of the scale, and then simply to determine the resistance value required to obtain a reading at the high end of the scale. This then gives a measure of the number of ohms per division represented by the recorder reading and that number, together with the initial value at the low end of the scale, allows determination of the actual resistance measured. This resistance is then translated using the temperature coefficient of the resistance thermometer into the actual temperature. By incorporating additional adjustments, one can arrange the bridge to measure temperature directly as, for example, 0 to 50 degrees for the full span of the recorder.

5. Chloride

Provisions are made on the chloride board to adjust the span and zero to allow setting a reference point according to measurements made on a specific pair of electrodes (Figure 39). The range is more than sufficient to allow measurement of any potential which the electrodes can produce.

6. Redox

Measurement of Redox potential is made by adjusting the zero and span controls to obtain zero volts at 5000 divisions and setting the span by applying a potential from a precision source to the reference and high impedance inputs (Figure 40). Conversion to millivolt readings is direct.

VI. DATA REDUCTION

The sequence for parameter readings is not critical except in the case of dissolved oxygen. The dissolved oxygen reading is always made last, since the stirring motor must be operating for at least one minute for the DO reading to stabilize. The water temperature is read first, because it is used as a correction factor for later readings.

A. Dissolved Oxygen

The number of divisions is read from the recorder tape. It is necessary to use the complement of the reading because the polarity is reversed. Also, the recorder is calibrated so that 10,000 divisions = 150 mV, and the measured value of the resistor is 50.75 K.

Therefore, since

$$E = \frac{10{,}000 - D}{10{,}000} \times 150 \text{ mV}$$

where D = number of divisions read, then

$$I_{\mu A} = \frac{\left(\frac{10{,}000 - D}{10{,}000}\right) \times 150 \text{ mV}}{50.75 \text{ K}} . \tag{1}$$

The current ($I_{\mu A}$) is related to parts per million of dissolved oxygen by the formula (7)

$$\phi = \frac{I_{\mu A}}{DO_{ppm}} \tag{2}$$

where $\phi = f(T)$, and T = temperature in °C.

From tests made in the laboratory, a curve typical of that shown in Figure 2 is plotted for ϕ vs T. Knowing $I_{\mu A}$ from equation (1) for a given temperature, the corresponding temperature is located on the curve and ϕ is read. Then, by substituting the known $I_{\mu A}$ and ϕ into equation (2), dissolved oxygen in ppm can be determined. In order to adapt this process for computer usage, it was necessary to obtain a polynomial expression for $\phi = f(T^{o}C)$.

Data for the electrode being used in the system yielded the following polynomial as a "best fit":

$$\emptyset = 1.7217\ (10^{-4})T^2 - 1.328\ (10^{-3})T + 6.356792\ (10^{-2}) \qquad (3)$$

Substituting this relation in equation (2) for Ø and substituting from equation (1) for $I_{\mu A}$,

$$DO_{ppm} = \frac{(10{,}000 - D)\ 150\ \text{mV}}{(50.75\ \text{K})(10{,}000)\ \left[1.72\ (10^{-4})T^2 - 1.33(10^{-3})T + 6.36(10^{-2})\right]} . \qquad (4)$$

The 150 mV figure is obtained by measuring the voltage across the servo potentiometer used to determine the voltage drop across the current sampling resistor.

The 50.75K value is the actual measured value of the nominal 50K current sampling resistor. The approximate range of current measurement is 0 to 3 microamperes.

B. pH

The equation for converting divisions read to a pH value is as follows:

$$\text{pH} = 7 + \left[\frac{\left(\dfrac{\text{Divisions Read}}{\text{Div./mV}} - 300\ \text{mV} + \text{Assymetry Potential}\right)}{54.19\ \text{mV} + 0.198\ \text{mV}\ (T)^{\circ}\text{C}}\right] . \qquad (5)$$

At a pH of 7 and at 25°C, the electrode system produces a voltage which is the asymmetry potential. If this voltage is +50 mV (typical), then the recording system will move downscale from 5000 divisions by 50 mV x 16.66 divisions. The recorder will read 5000-833, or 4167 divisions. Then

$$\mathrm{pH} = 7 + \frac{\left[\frac{4167}{16.66} - 300 + 50\right]}{54.19 + (0.198 \times 25)} = 7 \; . \qquad (6)$$

If, however, a solution of pH 5 is measured at 20°C, then the electrode system will produce a voltage of 116.3 mV + 50 mV, or 166.3 mV. The recorder will move 166.3 x 16.66 divisions downscale and will read 2229 which is 5000 div - (166.3 x 16.66 div) .

Then

$$\mathrm{pH} = 7 + \frac{\left[\frac{2229}{16.66} - 300 + 50\right]}{54.19 + (20 \times 0.198)}$$

$$= 7 + \left(\frac{133.8 - 250}{58.15}\right) = 5 \; . \qquad (7)$$

The 16.66 div/mV conversion is predicated on the following:

A. That 0.0 mV input gives a chart reading of 5000 div.

B. That +240 mV input produces a reading of 1000 div and a -240 mV reading of 9000 div.

The result is that the chart is calibrated to read ±300 mV fullscale with zero at the center. If readings other than 1000 div and 900 div are obtained, one may obtain the new sensitivity by dividing the difference in the two chart readings by the input voltage, i.e.

$$\frac{9025 - 975}{480 \text{ mV}} = \frac{8050 \text{ div}}{480 \text{ mV}} = x \, \frac{\text{div}}{\text{mV}} \; . \qquad (8)$$

Failure of the zero input voltage to produce a chart reading of 5000 can also be corrected, but the system should not be allowed to operate in such a manner because of the inconvenience caused and because of the probable malfunction causing such a reading.

The information needed to correct the equation (5), when electrodes are changed, is the new value of asymmetry potential, which must be measured in advance in the laboratory.

C. Conductivity

Conductivity is measured as a resistance and is corrected by the cell constant. A temperature coefficient correction may also be applied.

The bridge is calibrated using a precision decade box. The bridge is set to measure 0 to 1,000 ohms, 0 to 10,0000 ohms, or 0 to 100,000 ohms by choice of resistors on the parameter board. If, for example, the 0 to 1,000 range is in use, then one would set values of 50 and 950 ohms into the input.

If 50 ohms produce 500 div and 950 ohms produce 9628 div, then there are 0.0986 ohms/division.

If there is a reading of 2210 div, then 2210 x 0.0986 /div gives 218.6 ohms. Then the conductivity is

$$L_s = \frac{K}{R} = \frac{0.105}{218.6} = 480.3 \ \mu\text{mhos} \qquad (9)$$

(assuming the cell constant has been previously determined to be 0.105). The temperature coefficient may then be used to correct to standard conditions.

D. Temperature

The bridge used for calibration is adjusted to set the 0°C resistance value of the resistance thermometer at 500 divisions (3834 ohms). A precision resistance box is used to determine the resistance needed to move the recorder to a value around 9000 divisions. From the two resistance values, a calibration of the bridge is obtained, giving its reading at 0°C and its sensitivity in divisions per °C. The resistance thermometer has a temperature coefficient of 14.47 ohms/°C. Example: calibration gives 3834 ohms at 513 div and 4800 ohms at 9322 div. The sensitivity is $\frac{8809 \text{ div}}{966 \text{ ohms}} \times 14.47 \text{ ohms}/^{\circ}\text{C} = 131.97 \text{ div}/^{\circ}\text{C}$. Now if the recorder reading is 4153, then

$$\frac{4153 \text{ div} - 513 \text{ div}}{131.97 \text{ div}/^{\circ}\text{C}} = 27.6^{\circ}\text{C} \quad . \tag{10}$$

E. Chlorides

The chloride measurement is similar to that of pH. Voltage output varies from about 40 mV at 10^{-1} molar activity ppm of the Cl^- to 190 mV at 5×10^{-4} molar activity.

The nominal voltage output is 59.2 mV per decade change in Cl^- molar activity. Less output voltage change per decade change is available below 5×10^{-4} molar activity. Curve fitting must be employed in this region in order to translate the voltage measured into activity. For the linear portion of the curve,

$$\text{Activity} = 10^{-N}$$

where

$$N = \frac{E_{read} + 18.4 \text{ mV}}{59.2 \text{ mV}} \quad .$$

In terms of recorder readout,

$$\text{Activity} = 10^{-N}$$

where

$$N = \frac{\left(\frac{10{,}000 - \text{div read}}{10{,}000}\right) \text{x } 300 \text{ mV} + 18.4 \text{ mV}}{59.2 \text{ mV}} \quad . \tag{11}$$

The above assumes that the zero control has been used to set the output reading to 6,666 divisions in a 10^{-2} molar solution, corresponding to 100 mV.

APPENDIX I

Winkler Method of Oxygen Analysis

The "Standard Methods for the Examination of Water and Wastewater" (3) gives the procedure for the Winkler Analysis. However, it is more convenient to use the procedure described in Hach Chemical Company's Catalog Number Nine (27). The chemicals are packaged in polyethylene containers for ease of use with a standard 300 ml sample bottle. The titrating solution is phenyl-arsenene oxide (PAO) rather than sodium thiosulfate; the PAO does not require frequent standardization as does the sodium thiosulfate.

It might be more convenient to titrate 100 ml of sample instead of the 200 ml Hach suggests. If this is done, however, the oxygen concentration in parts per million will be twice the number of ml of titrant used (ml x 2 = ppm).

Dissolved Oxygen Titration Method Using PAO (27)

Procedure for Water and Sewage

1. Fill a standard 300 ml BOD bottle with the water to be tested by allowing the water to overflow the bottle for 2 or 3 minutes. Be certain there are no air bubbles present in the bottle. Add the contents of one manganous sulfate powder pillow (or 2 ml of manganous sulfate solution).
2. Add the contents of one alkaline iodide-azide powder pillow (or 2 ml of alkaline iodide-sodium azide solution) to the BOD bottle.
3. Restopper the bottle in a manner so as to exclude all air bubbles. Shake to dissolve the powder, and mix the floc that is formed. Allow the floc to settle about half way down the bottle (see Observation A).

4. Clip open one pillow of sulfamic acid powder (or add 2 ml of concentrated sulfuric acid). Remove the stopper and add to the sample bottle. Restopper, and shake to mix. The floc will dissolve and a yellow color will develop if oxygen is present.
5. Fill a 200 ml graduate to the 200 ml mark with the solution from the BOD bottle. Pour this into a 300 ml erlenmeyer flask.
6. Using the standard PAO solution, titrate the sample until it is pale yellow.
7. Add 2 ml of starch indicator solution. A blue color will be formed.
8. Continue the titration until the blue color just disappears.
9. The ppm of dissolved oxygen is equal to the number of milliliters of PAO used.

Observations

A. It is difficult to restopper the BOD bottle at this point in the test without getting an air bubble trapped in the bottle. To avoid the air bubble, incline the BOD bottle somewhat and insert the stopper with a quick thrust. This will force the air bubbles out.

B. The conventional 0.025 N sodium thiosulfate is listed in the alphabetical price list at the back of the Hach catalog (27). In this same listing is the standard iodate-iodide solution, equivalent to 10 ppm dissolved oxygen, which may be used as a routine accuracy and standardization check for standard sodium thiosulfate solution.

APPENDIX II

Rejuvenation of Beckman 76365 and 39065 O_2 Electrodes

The method for rejuvenating the Beckman 76365 or 39065 O_2 electrodes is as follows:

1. Remove the end cap, teflon spacer, and all O-rings; discard the old membrane (there is a small O-ring inside the end cap which should also be removed).
2. Both the cathode and anode should be thoroughly cleaned with Alconox and tissue paper. The O-rings should also be cleaned.
3. Rinse the electrode with distilled water, dry completely, and replace the large O-ring.
4. Cut a piece of Teflon membrane from the 3/4 mil roll large enough to cover the cathode and anode area.
5. Completely cover the cathode and anode with KCl gel; also, place a small amount on the membrane and place the membrane on the electrode.
6. Secure the membrane with the middle-sized O-ring and cut away the excess Teflon.
7. Carefully remove the excess gel from the electrode threads with the edge of a piece of tissue paper.
8. Replace the small O-ring in the end cap, replace the Teflon spacer, and screw on the end cap.

The following is a list of precautions which should be observed when rejuvenating the oxygen electrodes. The numbers correspond to the steps listed previously.

3. After the electrode has been cleaned, it should be recleaned if either the cathode or anode should be touched.
4. If, in this step and all subsequent steps, the portion of the Teflon covering the cathode should be touched, discard the teflon.
7. It is very important to remove all the excess gel from the area of the threads; otherwise, there may be an electrical connection between the electrode and the solution.
8. As the end cap is replaced, observe the Teflon in the area of the cathode; the cap should be screwed so tightly that the membrane turns milky in color over the cathode. If it is felt that the cap is not yet sealed against the O-ring and the membrane is turning milky, silicone grease can be used to seal the cap; however, during the next rejuvenation, one must be very careful not to get the grease on the electrode.

High residual current may be caused by the separation of the metal portions of the electrode from the plastic surrounding them. Close examination of an electrode with high residual current will usually indicate a crack at one of the joined surfaces. The electrode must be discarded if this is the cause of the high residual current. If, however, this does not appear to be the case, one may attempt to salvage the electrode by the following procedure:

1. Attach a piece of silver wire to the positive terminal of a 6-volt dry cell battery and place the free end in a 10%

KCl solution.

2. Connect the silver anode (red) lead to the negative terminal of the battery.
3. Immerse the electrode in the KCl solution and allow the current to pass through the sensor for approximately 30 minutes. The solution should be stirred.
4. It is possible that some foreign material will be deposited on the cathode. In order to clean the cathode, proceed as follows:
   (a) Connect the auxiliary silver wire with the negative terminal of the battery and the cathode (black) lead with the positive terminal of the battery.

   (b) Immerse the electrode in the KCl solution for not longer than 15 seconds.

   (c) Change the polarity by reversing the battery connections (15 seconds).

   (d) Rinse the electrode with a solution of sodium thiosulfate, wash with Alconox and rejuvenate as indicated above.

APPENDIX III

Photographic Digital Recording

The recording of data at remote locations is a serious problem that must be contended with during the development of a system of the type described in this report. A number of methods have been investigated, one of which was the recording of data in digital form on film. Some of the desired requirements for a recorder of this type were that it be mechanically simple, inexpensive, and reliable. It should use commercially available standard grade film and a minimum of optical components should be involved.

The design of a camera that fulfills these requirements evolved during this contract (Figure 42). The feasibility of recording information on film was proven but it was not incorporated into the system since the perforated tape recorder was operating adequately and it would have required development of a tape reader compatible with the photographic recording.

The camera used 35mm film and was driven by a stepping motor. The incremental steps can be regulated by the use of a gear reduction between the motor and the drive sprocket. Figure 43 is a recording that was obtained at approximately 0.03 inches/step. No optics were used other than stops. The light sources used were subminiature low power lamps. There was a lamp for each bit.

The circuitry utilized in the recorder consisted of an A/D converter and the driver stages for the lamps. The input signal was converted into parallel, binary or binary coded decimal, as desired, and applied to the lamps for periods ranging from 1/100 sec to 1/2 sec (Figure 43). The correct exposure time is a function of the aperture size and of the power level at which the lamps are operated.

The stepping motor used to drive the film moved in 1.8° increments. It was a somewhat more sophisticated motor than necessary in that it required a specific switching sequence between the various windings. The circuitry to provide the switching became complicated and after some experimentation it was determined that, by using the appropriate gear reduction, a simpler stepping motor could be used. This requires a pulse of at least 50 millisecond duration to be applied to a single winding for each step.

Several improvements could be made in the photographic recorder. Greater recording density could be achieved by use of an optical lens system to focus the light to a point, thereby allowing more "words" to be recorded per unit distance. This would place stringent requirements on the film reader, but a satisfactory compromise should be at least 100 lines of information per inch. This would allow approximately one week's recording of 5 parameters 4 times an hour on a 33 inch film strip.

The most critical aspect of the recorder was the film drive mechanism. It proved to be difficult to advance the film in very small steps with no backlash or with no variation in the spacing between the "words". However, a satisfactory recorder undoubtedly could be built that would allow high density recording at very low power consumption levels.

APPENDIX IV

Experimental Turbidimeter

In order for a turbidimeter (28) to meet the needs of this project, the problem imposed by fouling of entrance and exit optics in contact with the water due to algae, dirt accumulation, etc., must be overcome. In addition, the turbidimeter must operate 30 days without attention. These requirements imposed the condition of probable drift in light source intensity, power supplies, and detector systems.

The following scheme was proposed in an attempt to meet these requirements: with a sample of given turbidity there is a unique ratio of transmitted light to scattered light, i.e., transmitted light will have some intensity and scattered light will have some intensity. Since these numbers have unique values and are in the same units, there will be a multiplying factor between them.

If m = Intensity of scattered light

Km = Intensity of transmitted light

$$\text{Ratio} = m/Km = 1/K = \frac{\text{Scattered light intensity}}{\text{Transmitted light intensity}} .$$

Two conditions are illustrated: Figures 44 and 45.

Let the percent of light passing exit window 3 be A and the percent of light passing exit window 4 be B.

For condition 1, the scattered light is received at detector 1.

Light reaching detector 2 = A

Light reaching detector 1 = B x K

$$\text{Apparent ratio} = A/BK = \frac{\text{Scattered light intensity}}{\text{Transmitted light intensity}} .$$

For condition 2, scattered light is received at detector 1 and transmitted light at detector 2.

$$\text{Light reaching detector 1} = B$$

$$\text{Light reaching detector 2} = A \times K$$

$$\text{Apparent ratio} = B/AK = \frac{\text{Scattered light intensity}}{\text{Transmitted light intensity}} .$$

$$\sqrt{(\text{cond. } 1)(\text{cond. } 2)} = \sqrt{A/BK \cdot B/AK} = \sqrt{1/K^2} = 1/K .$$

Therefore, 1/K represents the square root of the product of individual ratios and this is the true ratio.

Consequently, the following assumptions must be examined:

1. Turbidity is defined if a ratio of light intensities representing the ratio of transmitted light to light scattered can be determined.
2. Changes at the entrance windows act as a change in source intensity and affect the transmitted light and scattered light identically so the ratio is unaffected.
3. Changes at the exit windows may be ignored by taking the apparent ratio for each path alternately, multiplying, and taking the square root, thus determining the true ratio.
4. Since ratios are used, changes in light source intensity, drift in power supplies and changes in solution other than turbidity, such as color, all cancel.

Description of Proposed Turbidimeter:

An x-shaped baffle painted black was placed in the cell in order to reduce multiple reflections within the cell. Thus, the scattering volume was confined to the size of the openings in the baffle.

The liquid cell, painted black except for the window on each of four sides, is open on top and is equipped with a stopcock drain on the bottom (Figure 46). Therefore, the cell could remain in the optic path and be drained through the stopcock.

The CdS detector used in the system was an RCA 7163 (Figure 47).

Procedure for Testing the Foregoing Assumptions:

A solution of known turbidity in terms of Jackson Candle units was introduced into the liquid cell. The cell was then closed and made light tight. One light path was closed off and the other opened. The potentiometer was adjusted until the DVM read zero. Calculation of the resistance ratio was made by the bridge formula. The procedure was repeated with the other light path and detectors reversed by the DPDT switch. These two ratios were then multiplied and the square root taken.

Experimental Results

The following studies were made:

1. The calibration curve for Jackson candle unit turbidity vs added solids was established.

Since skim milk provides stability, it was used to prepare turbid solutions. Solutions with measured volumes of skim milk per liter were prepared and the Jackson candle turbidity determined for each. The purpose of this test was to be able to prepare artificial solutions and know the Jackson candle turbidity without the necessity of calibrating each time.

Also, solutions of Wyoming Bentonite were prepared and the Jackson candle turbidity for these was determined. Solutions of bentonite were used for all later work. These solutions were prepared fresh for each run.

2. The relation between the $\frac{\text{Scattered light intensity}}{\text{Transmitted light intensity}}$ ratio and Jackson candle turbidity was studied.

Suspensions of skim milk or Wyoming Bentonite were prepared determinately by volume of skim milk or weight of bentonite per volume of water. The suspensions were used in a standard Jackson Candle Turbidimeter to obtain the calibration curves shown in Figures 48A and 48B. These suspensions were introduced into the apparatus and the resistance ratio of the two photocells was determined by nulling the Wheatstone Bridge. The resistance ratio is inversely proportional to the $\frac{\text{Scattered light intensity}}{\text{Transmitted light intensity}}$ ratio since the photocell resistance decreases with greater light intensity falling on it.

The plot of Jackson Candle turbidity vs the resistance ratio is shown in Figure 49.

This method of measuring turbidity is a standard one. Tyndallometers use scattered/transmitted light ratios commonly since they are used where turbidity is very low and the transmitted light is indistinguishable from the incident light. For higher turbidities, the incident light is measured and the scattered light or transmitted light is measured relative to it. Thus, it is not common to apply the scattered/transmitted light ratio to as wide a range of turbidity as is done here. This ratio is needed for the compensation argument since light ratios must be used which have been exposed to the same optic paths. It is likely that, as very turbid solutions are measured, light would not reach either detector and measurement would be lost. A practical upper limit was reached in these experiments as 20 grams of bentonite per liter was the greatest amount that would go into suspension.

This method of measurement was known to be valid at low turbidity. The purpose of this series of measurements was to determine if the apparatus as constructed would measure in a reasonable manner.

The plot in Figure 49 shows that a better fit to a curve is obtained from skim milk. This is probably because the skim milk is a stable suspension initially and is then diluted to obtain lower turbidity. In the case of Bentonite, a solid is placed in water and shaken to obtain a suspension. The measurement may be better than the calibration in this case. The best fit indicates an equation of the form $Y = cx^n$.

Turbidity shifts considerably from suspensions of skim milk to suspensions of bentonite when calibrated against Jackson Candle units. Turbidity as measured by tyndallometry is proportional to the cube of the particle size. Particle size for the two suspensions is not known, but may account for the shift. Bentonite was used in later work bacause it was believed that the bentonite would more nearly represent a stream sediment.

3. The stability of measurement to source lamp voltage change was studied. The lamp used was the 6V lamp used in the Beckman DU Spectrophotometer. Tests were made with the lamp voltage adjusted to 4V, 5V, and 6V. As the lamp voltage is dropped, the wavelength of light emitted shifted to the red, or longer wavelengths. Turbidity as measured by tyndallometry is inversely proportioned to the fourth power of the wavelength. That is, if scattering particles are held constant, the scattered/transmitted light ratio decreases with wavelength. The number plotted in Figure 50 comes from the ratio of resistances which is inversely proportional to light intensity. Thus, the relation found is in agreement with expected results. Therefore, the measurement is adequate if lamp voltage is held between 5V and 6V.

4. The stability of measurement to entrance optic change was studied. Filters were prepared by exposing film strips to light and developing. The o/o transmission of these filters was measured on a densitometer. The following filters were used:

1. No filter
2. 100% filter (film not exposed to light before developing)
3. 85% filter (85% transmission)

4. 50% filter (50% transmission)
5. 27% filter (27% transmission)

These filters were placed at entrance windows 1 and 2 and measurements were made. The purpose was to simulate fouling of the entrance window.

The effect here was much the same as changing the lamp voltage. This was somewhat surprising as these filters should be neutral, affecting only the intensity of light rather than shifting the wavelength as decreasing lamp voltage does. However, the difference from no filter to 27% filter is no greater than the reading error on the Jackson Candle turbidimeter. The points at 3.9 and 7.8 J.C.U. fall off the curve due to an error in working up the solutions. Curves shown in Figure 51 were drawn for the extremes.

5. The stability of measurement to changes at the exit windows was studied to determine if different degrees of fouling at the exit windows could be compensated for with this ratio. The curves and conditions under which they were obtained are shown in Figure 52. Compensation was good for this case and much better than for the entrance window case.

6. The stability of measurement to change in detector power supply was determined. This experiment was based on the assumption that the detectors would be used in a bridge circuit (Figure 47). The assumption was that a servo potentiometer would be used to balance the bridge. The test concerned whether or not power supply (represented as the Hewlett Packard supply in Figure 47 drift would affect the measurement. Tests were made at 15V and 20V. No change was detected (Figure 53).

Conclusions:

Figures 54 and 55 show all extreme points and many other points for all sets of results obtained. Figure 54 shows all ratios. Each measurement consisted of two ratios, one for each light path. Previous graphs have shown the square root of the product of these two ratios plotted against Jackson Candle units. Each individual ratio is plotted in Figure 54.

Figure 55 shows the square root of the product for extremes of all results.

A comparison of Figures 54 and 55 shows that the compensation approach results in significantly close results at higher turbidity but is of much less advantage below Jackson Candle Units of turbidity.

The most serious factor affecting results at lower turbidity is lamp voltage. It is unlikely that lamp voltage would vary to the extremes used, and results would probably be much better than shown.

Compensation for fouling of windows is fairly good, but under some conditions encountered in streams where fouling growth rate was rapid, transmission was too low to allow continued operation in less than one week. A different approach is indicated for such situations.

APPENDIX V

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DEVELOPMENT AND PERFORMANCE OF A MOBILE WATER QUALITY MONITOR

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ABSTRACT

A mobile water quality monitor intended for extended unattended use in locations where power lines are not available and for survey use is described. All solid state electronics are employed. Field tests have been performed for the past 2½ years. Conclusions and problems concerning the monitors and transducers will be reviewed. Suggestions for future development are given.

INTRODUCTION

A need exists for water quality monitoring equipment to allow data to be taken at locations where no permanent installation is desired, or where the access to power lines makes installation of conventional equipment inconvenient. The equipment is intended for use at sites where data taken for an extended period of time is desired, in contrast to that available from grab samples or from on-site man operated equipment.

Requirements

Transportation and installation of the equipment at the survey site should be possible using no more than 2 men, and servicing should be feasible by a single person. Calibration of equipment should be possible in a simple fashion since remote location of the equipment and the potentiality of adverse weather conditions make calibration difficult. The equipment should accept replacement transducers without a major adjustment of the on-site monitor, since at the present time the operational lifetime of the transducers is considerably less than one might require. Since it is desirable to handle the collected data by a digital computer, the information recorded should be in such a form that it may be easily translatable for computer use. Often the requirements for measurements to be made may differ from one location to another; therefore, the instrument should accommodate as many combinations of different transducers as possible. It is also desirable that as much of the equipment as feasible consist of "off the shelf" items, particularly the transducers. Cost is also considered a factor, since a quantity of these units may be required for use in many different locations.

DESCRIPTION OF THE MONITOR

Measuring System

The following units comprise the monitoring system as it has evolved (Figure 56). Each transducer is connected to its own special signal conditioning board (29). These boards are connected in turn by an internal programmer to a common amplifier. This amplifier drives a servo motor which simultaneously drives a binary coded decimal punched paper tape recorder and the null balance or potentiometric servo potentiometer. Power is supplied by a 12 volt storage battery which is intermittently recharged by a gasoline driven motor generator set. All of this equipment is mounted in a small covered boat (Figure 57). System timing is controlled by a highly accurate battery operated clock. Information is recorded in binary coded decimal form onto punched paper tape. Data recording resolution is 1 in 10,000. The data are translated and any corrections are applied automatically by a reader-computer combination.

Transducers and Circuits

The transducers described in the following material were chosen on the basis of reliability in long term operation, availability, suitability for use in a mobile instrument, and cost. The circuits required to interface between the measurement equipment and the transducer were chosen on a basis of simplicity, ease of calibration, and their likelihood of providing a reliable measurement under conditions of varying ambient temperature and humidity. Wherever possible, measurements are made in potentiometric or null sensing manner in order to reduce dependence on supply voltages and variation in gain of the amplifiers involved.

Temperature

The transducer chosen for the measurement of temperature was a nickel alloy resistance thermometer. Resistance thermometers are available, sufficiently well characterized, to allow replacement of one unit with another without the necessity for changing zero or span adjustments. The fact that they measure temperature by means of a change of resistance allows their use in a bridge configuration. Since an AC bridge configuration was necessary for the measurement of conductivity, a similar bridge was chosen for use in temperature measurement. However, the bridge for temperature measurement is an expanded scale version allowing expansion of the desired temperature range over the full range of the recording system employed. Calibration is possible by means of a pair of precision resistors which may be substituted in turn to obtain a two-point calibration of the measurement circuits.

Conductivity

A platinized platinum epoxy dip type conductivity electrode was chosen because of the wide range of conductivities encountered in different areas. Methods were investigated that did not involve the use of electrodes, but they did not have sufficient range to permit wide spread use, and were found to have non-linear response characteristics requiring extensive and complex calibration. It is possible that the platinized platinum electrodes may prove unsatisfactory in the case of certain specific pollutants. However, our experience with the lifetime of these electrodes has been good for natural streams not possessing these specialized pollution problems. Because of conduction polarization effects, it is necessary to measure conductivity using an AC bridge. The bridge circuit chosen was a null balance type, making it essentially independent of bridge excitation voltage values as well as amplifier gain characteristics. Variations in these factors will at worse only degrade slightly the accuracy of the measurement involved. Once again, calibration is possible using fixed precision resistors. Provisions are made on the conductivity circuit board to change ranges by a factor of 10 in either direction from the original cell constant in order to allow use of the same cell constant electrode for a relatively wide variety of measurement situations.

pH

The measurement of pH is a very high impedance measurement of a relatively high level output voltage. Consequently, special provisions are made at the input to the circuit boards to maintain large values of insulation resistance. Since these same precautions are necessary for the measurement of chlorides and other ions, half the input channels to the monitor are provided with special circuits for measurements possessing requirements similar to that of the pH electrodes. The signal measurement is made as a potentiometric null balance measurement by comparing the output voltage of the pH electrode with a voltage obtained from a high precision temperature compensated zener diode reference. These reference diodes are available at reasonable cost, and allow the introduction of precision voltage reference values to the circuit without excessive cost penalty. Since the servo system is an AC system, it is necessary to chop the DC error signal in order to produce an AC signal for the servo. All DC signals are routed through this chopping path and thence fed to the AC circuitry used for the previously described DC voltage measurements. The signal chopper compares the voltage from a servo driven potentiometer having a known full scale voltage response with the signal from the transducer. No attempt is made to correct for the effects of temperature on the transducer in the field. The information thus recorded is taken from the tape and correction factors for temperature as well as any other anomalies of electrodes involved are applied by computer data reduction.

A Beckman low impedance process type glass electrode is used together with a liquid junction, process type palladium annulus reference electrode. It was found necessary to pressurize this reference electrode with approximately 10 psi air pressure in order to obtain consistent flow of KCl solution out of the electrode. In the absence of pressurization, the electrode tends to plug over a period of 6 weeks or two months when exposed to field situation where algae and bacteria growth are heavy.

Dissolved Oxygen

Two dissolved oxygen electrodes have been used in the system. One is galvanic - of the type described by Mancy (7), Mackereth (6), and Briggs (30). The version tested is made by E.I.L. of England. This Mackereth type electrode has given the longest satisfactory service of any of the electrodes tested to date. A second electrode which has been used and which has given better lifetime than others tested previously is a Beckman large cathode version of the polarographic electrode of the type described by Carrit and Kanwisher (8).

The Mackereth electrode is a current-producing electrode requiring measurement of the short circuit current generated. Consequently, the output current from this electrode is treated on the printed circuit board designed for this electrode by an operational amplifier serving as a current to voltage converter (Figure 58A). This voltage is then measured by conventional potentiometric means as described previously and translated to a data point at the output of the servo amplifier which is directly proportional to the current produced by the electrode.

The second electrode which has been used in the system is the polarographic type requiring the application of a polarizing voltage and measurement of the current produced. Measurement of this current is performed in the same fashion as that of the galvanic electrode, and the polarizing voltage is applied from the output of the second operational amplifier located on the circuit board (Figure 58B).

Both of these electrodes are highly sensitive to temperature changes, the major effect being that of a change in diffusion rate of oxygen through the membrane with temperature. When the ratio of the cell current to parts per million of oxygen is plotted versus temperature on semi-log paper, a straight line results; this line is known as a Ø curve. For both electrodes, a Ø curve is constructed for each specific electrode. This requires measurement [illegible] laboratory of the current produced by the electrode at a minimum of 2 different temperature points since the signal produced in linear with oxygen concentration. These points allow the construction of a so-called Ø curve which gives the relationship between parts per million oxygen, current, and temperature. This Ø curve is used by the operator in the field to translate his recorder readings to dissolved oxygen for cross-checking with Winkler's done in the field, and is also used by the computer to correct readings for temperature when the data tape is returned to the laboratory. A large number of these Ø curves constructed over a period of time demonstrate that the slope of the correction curve is very consistent, and sufficient operating experience might allow one to construct a Ø curve using only one reading.

Programmer Timing and Sequencing

The primary timing device used to control the basic timing sequence of the monitor is a battery powered sequence timer made by Geodyne Corporation. The clock is a chronometric 15-jewel, temperature compensated movement which operates a single-pole, double-throw switch. Upon command by the timing clock, which determines the measurement interval and its absolute time, the programmer sequences through a set of six parameters allowing a 30 second measuring interval for each. During a given 30 second interval, the parameter board is connected to the power supply and amplifier, and the servo system is allowed 20 seconds to attain null balance. Following this, the reading present at the output of the recorder is locked into place and punched into the paper tape. The programmer then selects the next parameter and the same sequence is repeated. A complete cycle requires 3 minutes, and provisions are made to perform this cycle at intervals of 15 minutes, 30 minutes or 60 minutes. This system can also be expanded to measure more parameters by changing the programming timing and connecting more signal conditioning boards into the input circuitry.

Power Supply

The gasoline motor generator set (a Kohler Model 500BE1) used for supplying power was chosen on the basis of off the shelf availability and cost versus lifetime. Consideration was given to thermoelectric generators and solar cells as possible power sources. Thermoelectric generators were tested and it was found that the decay rate of the power output would make this method of power generation quite expensive. Solar cells were also considered; however, in view of the power required for supplying sufficient sample flow for reliable operation of the oxygen electrodes, the number of solar cells and surface area would have been excessive. The motor generator set is modified to charge two batteries in parallel. One of the batteries is used to operate the electronic circuitry in the equipment, and the other is reserved only for generator starting purposes. It was found that use of a single battery after it was partially discharged did not provide reliable starting of the motor generator set. The storage battery, upon command of the programmer, is connected to a DC to AC sine wave solid state converter and produces 115 AC power. This AC power is then used to operate a series of small power supplies at different voltage levels for the remainder of the electronic circuitry. It also allows isolated supplies to be generated which are required because of grounding problems encountered in the measurement of those parameters where the electrodes involved must float electrically off of ground. The motor generator set is a nominal 500 watt unit, and it runs approximately 1½ hours out of every 24 hours in order to recharge the main storage battery. Gasoline consumption is less than 5 gallons per week.

Operation

The system has operated for varying periods of time up to a maximum of a interval 6 months in the field. The circuits, switching and relays all prove completely reliable. Reed relays are used in sensitive signal areas and IBM type wire contact relays are used for other switching purposes. No failure in any of these components occurred nor did any of the amplifiers or power supplies in the system fail.

There were occasional failures of electrodes in the field. A resistance thermometer opened for no known reason. Some failures could be attributed to operator error such as failure to recharge the reference electrode, air supply, and on one occasion some unknown creature filled the conductivity cell with eggs. At an earlier stage, when dissolved oxygen electrodes using small cathodes were in use, frequent failures of these electrodes occurred. Probably the most troublesome problem occurring in the field was failure of the motor generator to start when commanded to do so. This problem has been partially eliminated by the introduction of the second battery for starting purposes only, and the addition of forced air cooling to the engine compartment when environmental temperatures rose excessively.

Future Work

Studies of an updated system are presently taking place in our laboratories. The recent decreased costs of operational amplifiers and digital integrated circuits allow one to approach the measurement problem in a different manner than previously possible. This laboratory is presently working on a system using integrated circuits with conversion of the transducer information from analog to digital form immediately at the transducer signal output. This digital information would be stored on a magnetic tape recorder - an integral part of the equipment. Data are stored on cassetes. Because of the high speed of operation possible, the total power consumption will be very low and it should be possible to perform these measurements using only batteries to supply the power required. However, this approach is made possible only by the fact that this laboratory has found a technique to eliminate the necessity for generating a sample flow rate past the dissolved oxygen electrode. This method is described in a paper presently in press (10). The system will not contain any switches other than solid state types, and its timing will be controlled by a crystal oscillator clock with time being recorded along with the other information as measurements are made.

CONCLUSIONS

The described system has been operated in the field, and the following capabilities have been established: pH measurements have been achieved to an accuracy of 0.1 pH unit for 4 to 6 months before changing electrodes. Conductivity measurements were attained to within ±5% for 6 months. The accuracy of the dissolved oxygen measurement was 0.25 parts per million for 2 months. The measurement of chlorides was within ±5% for 3 months; and temperature was measured to an accuracy of ±0.1°C indefinitely.

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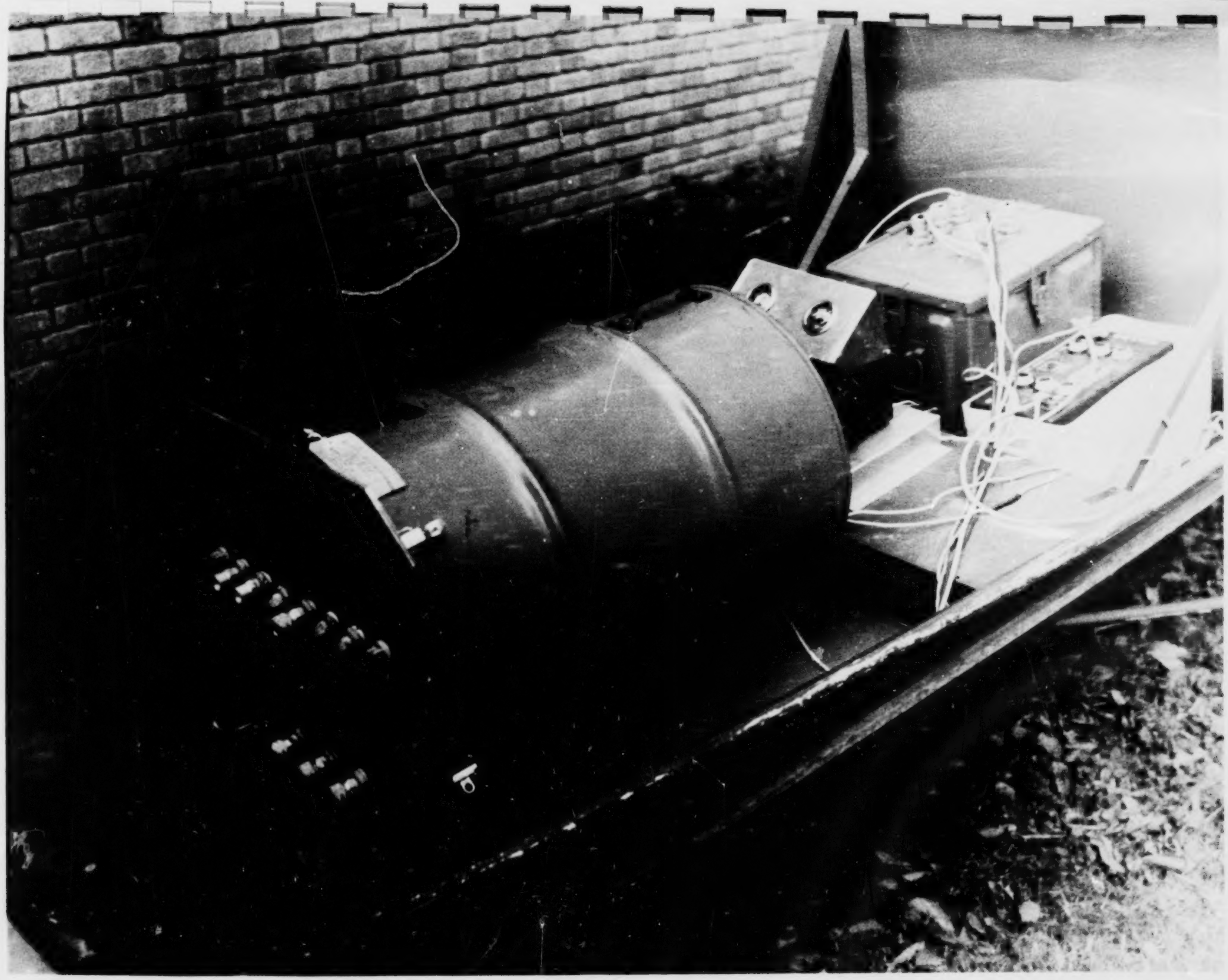


Figure 1. Internal Parts Location

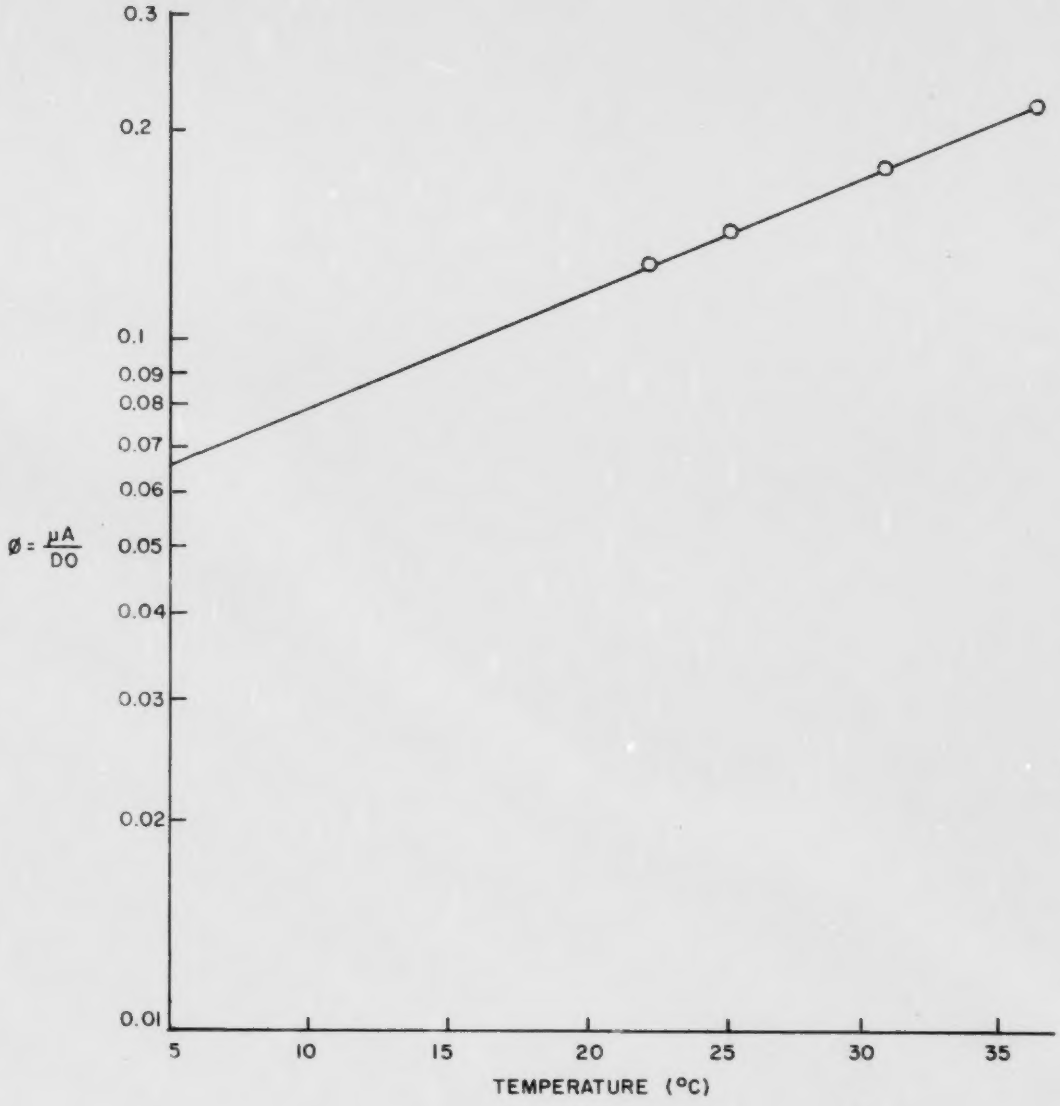


FIGURE 2

CALIBRATION CURVE FOR BECKMAN DO PROBE NO. 76365 —
PROBE VOLTAGE - 0.8V

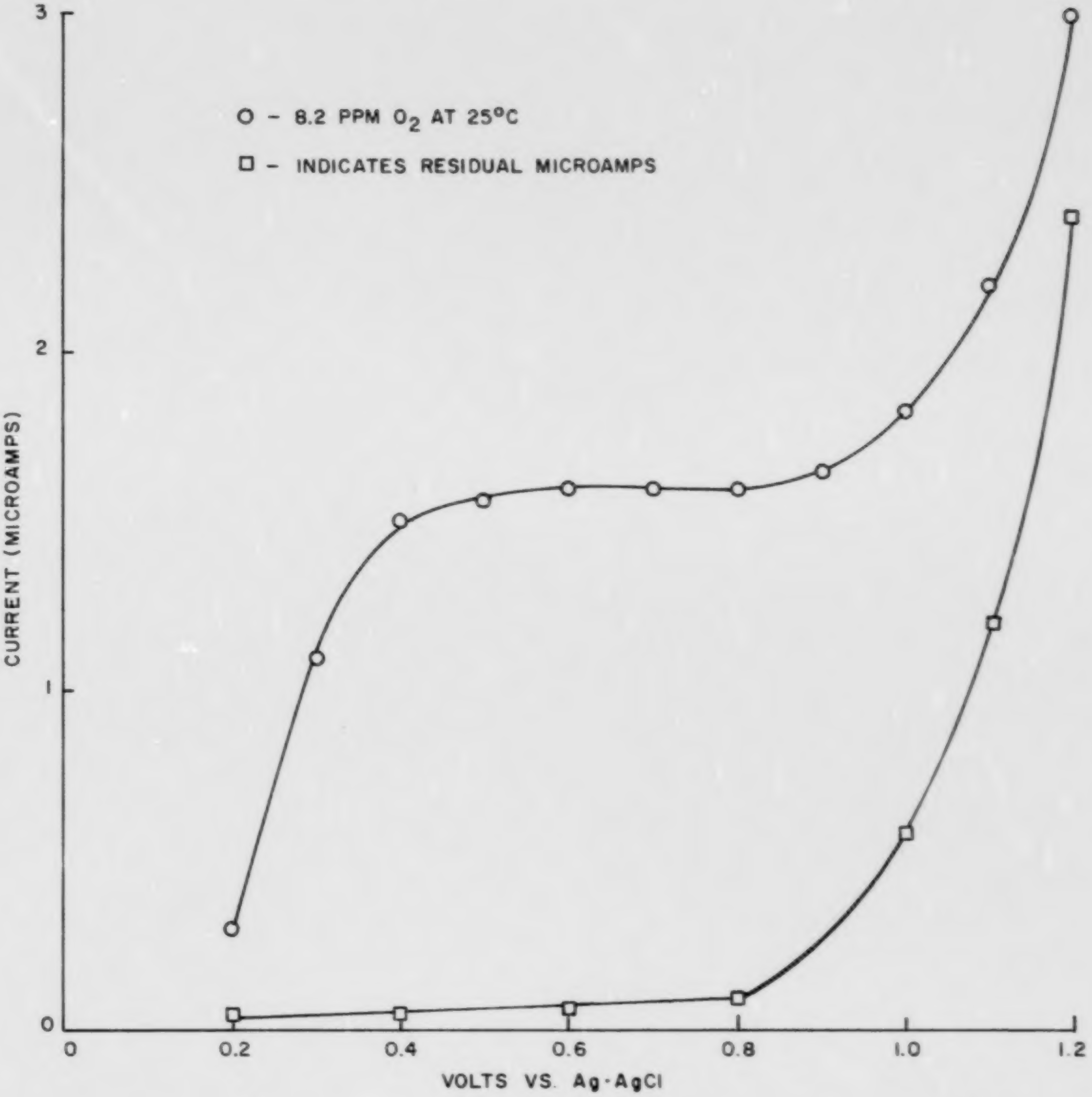


FIGURE 3

CURRENT-VOLTAGE CURVES FOR BECKMAN ELECTRODE (RHODIUM CATHODE) VIA CHRONOPOTENTIOMETRY

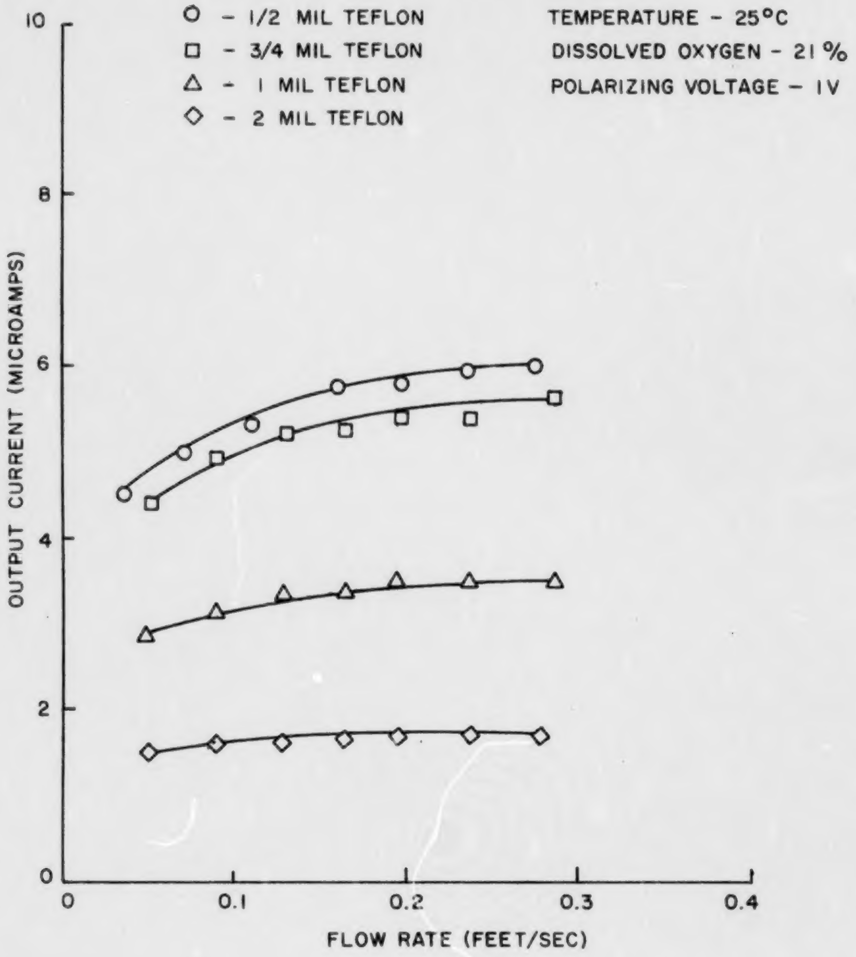


FIGURE 4

FLOW RATE VS CURRENT OUTPUT – ELECTRODE SIZE = 0.1 INCH

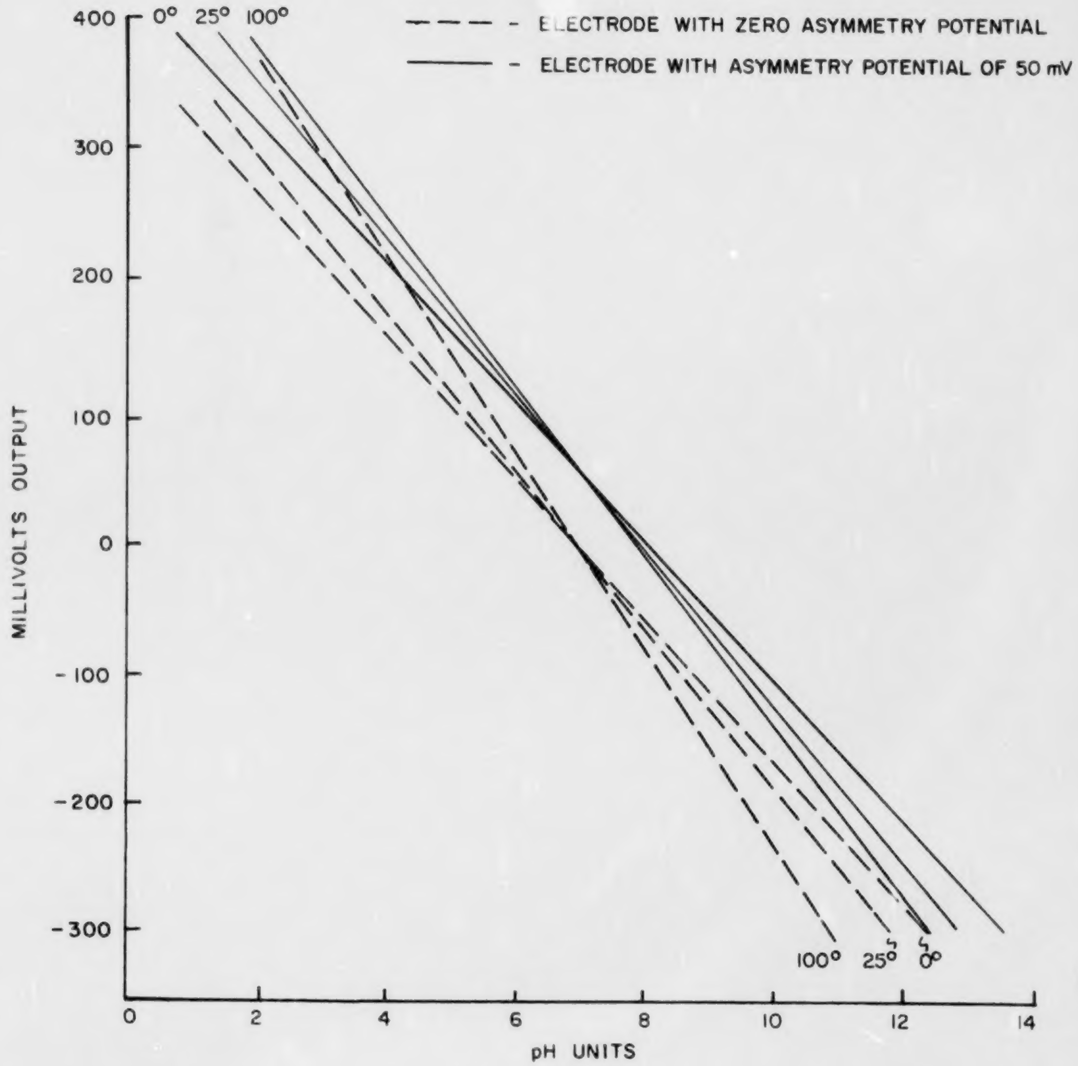


FIGURE 5

OUTPUT VOLTAGE VS pH UNITS FOR TWO ELECTRODES WITH DIFFERENT ASSYMETRY POTENTIALS

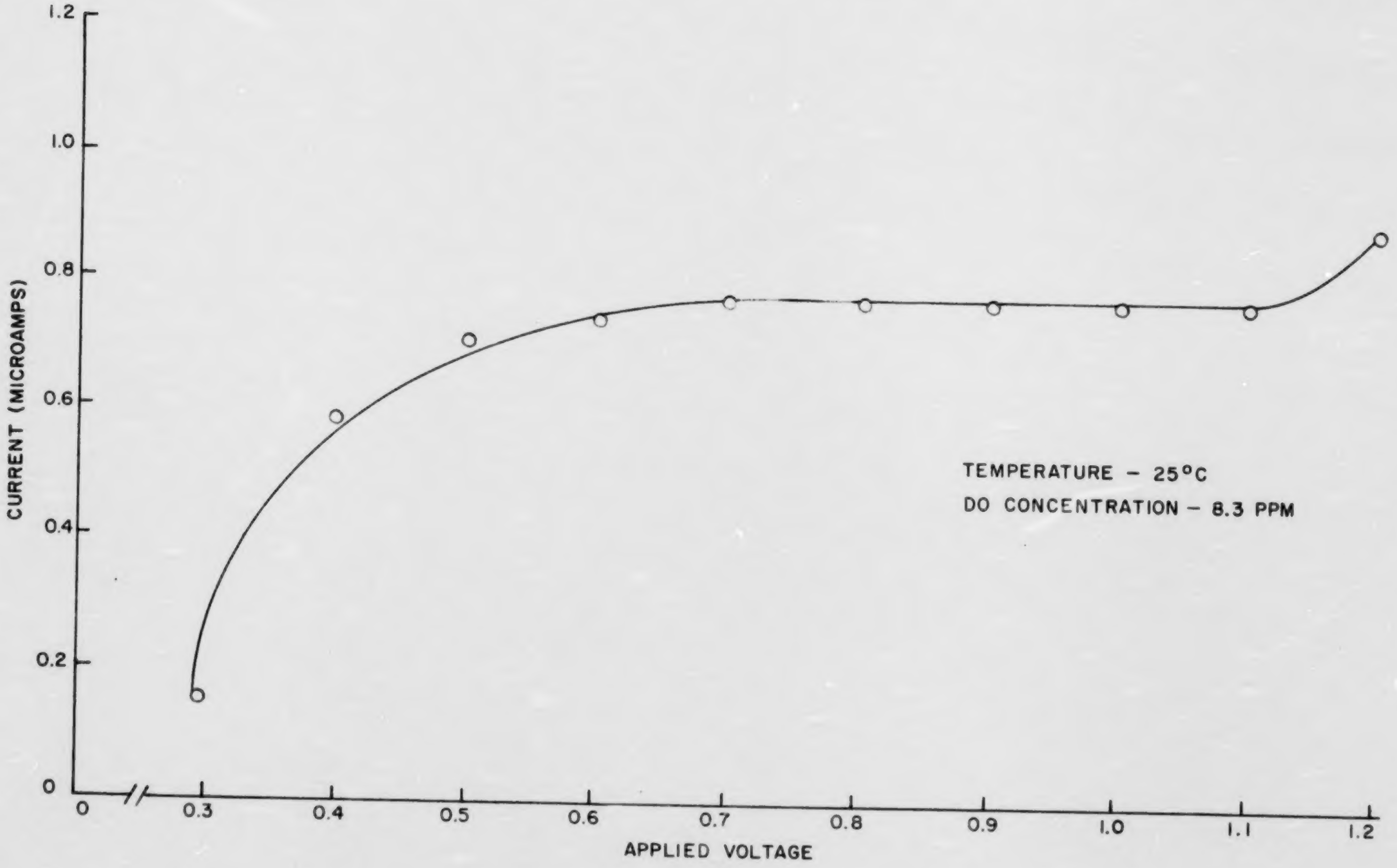


FIGURE 6

PLATEAU CURVE - BECKMAN DO PROBE B7-2

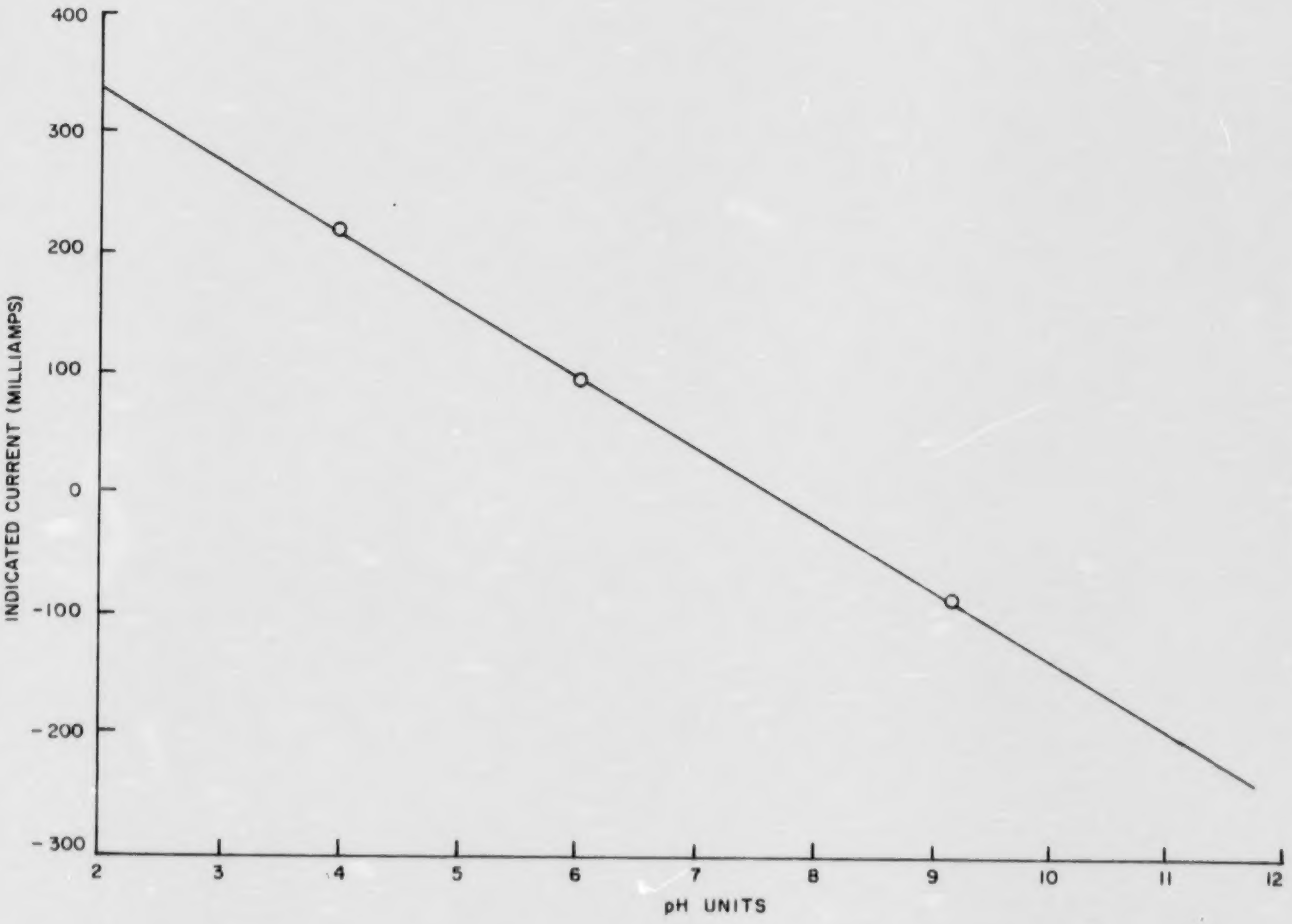
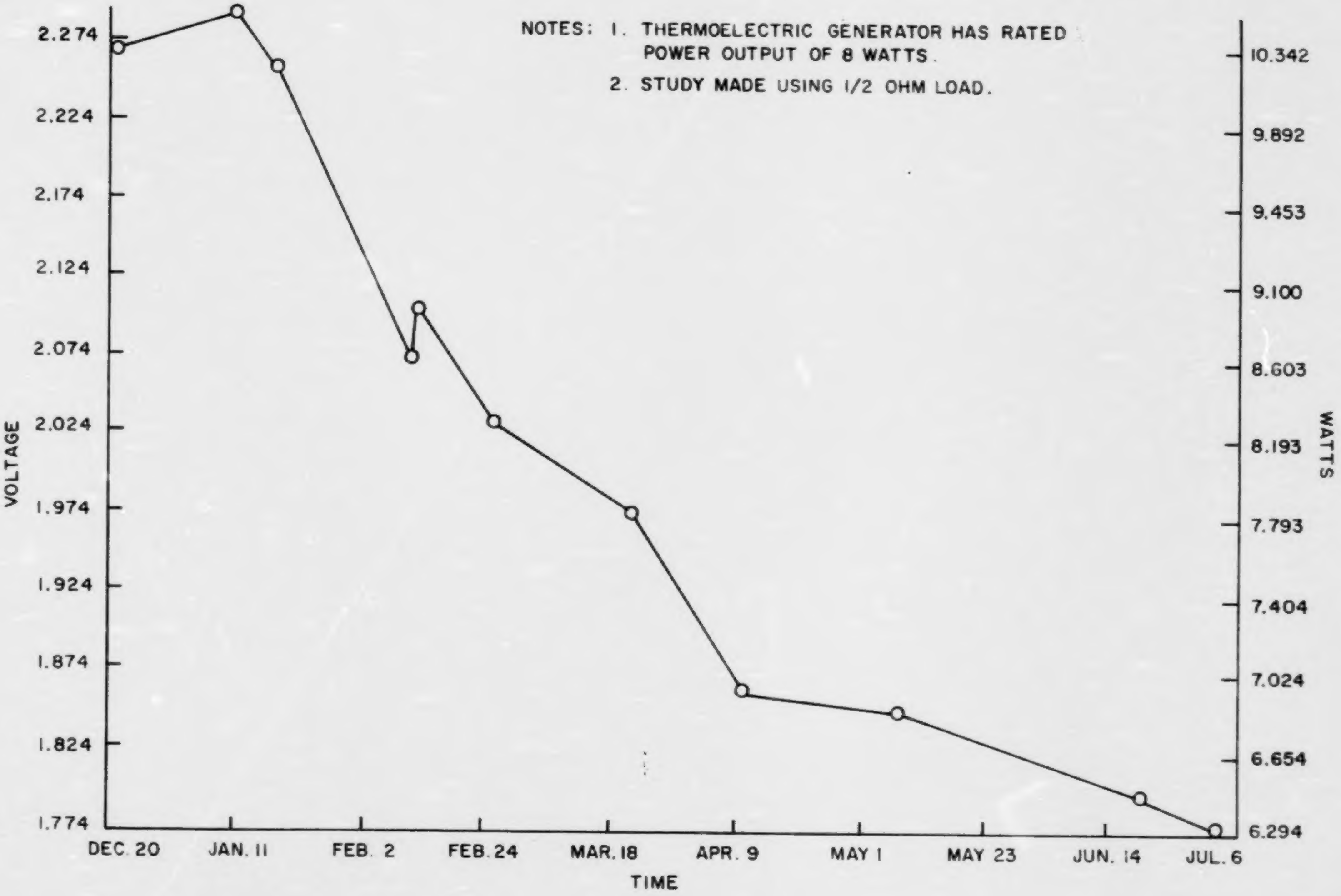


FIGURE 7

CALIBRATION CURVE – BECKMAN ELECTRODE 19500, REFERENCE ELECTRODE 19500



NOTES: 1. THERMOELECTRIC GENERATOR HAS RATED POWER OUTPUT OF 8 WATTS.
2. STUDY MADE USING 1/2 OHM LOAD.

FIGURE 8

SERIAL NO. 185

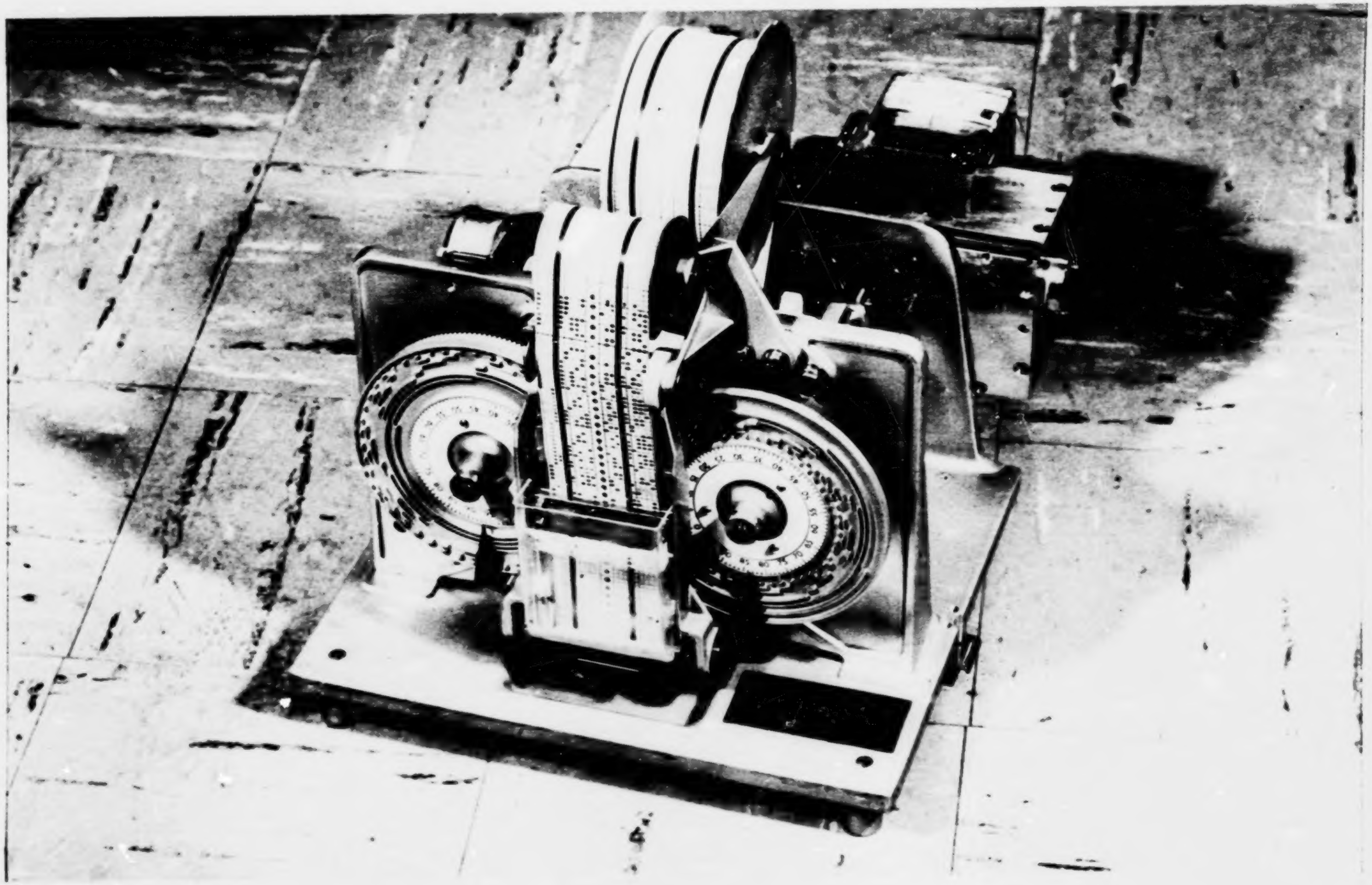
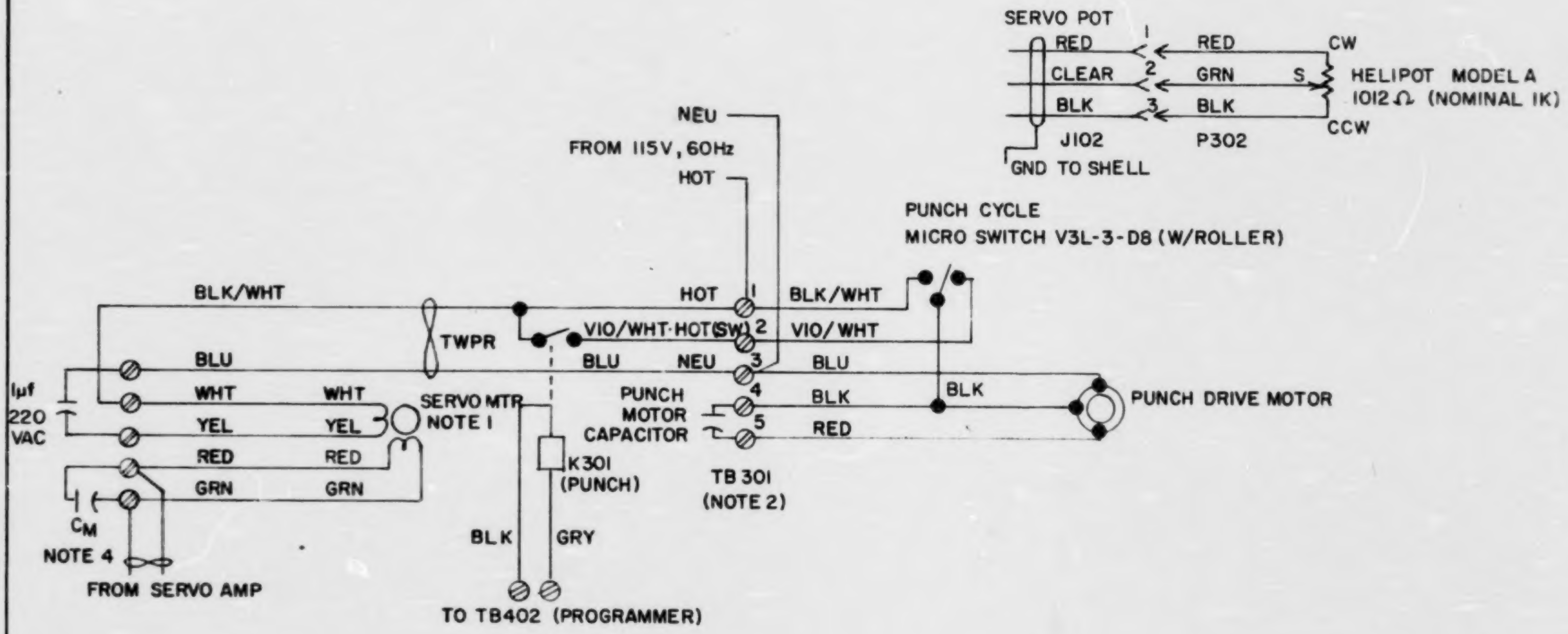


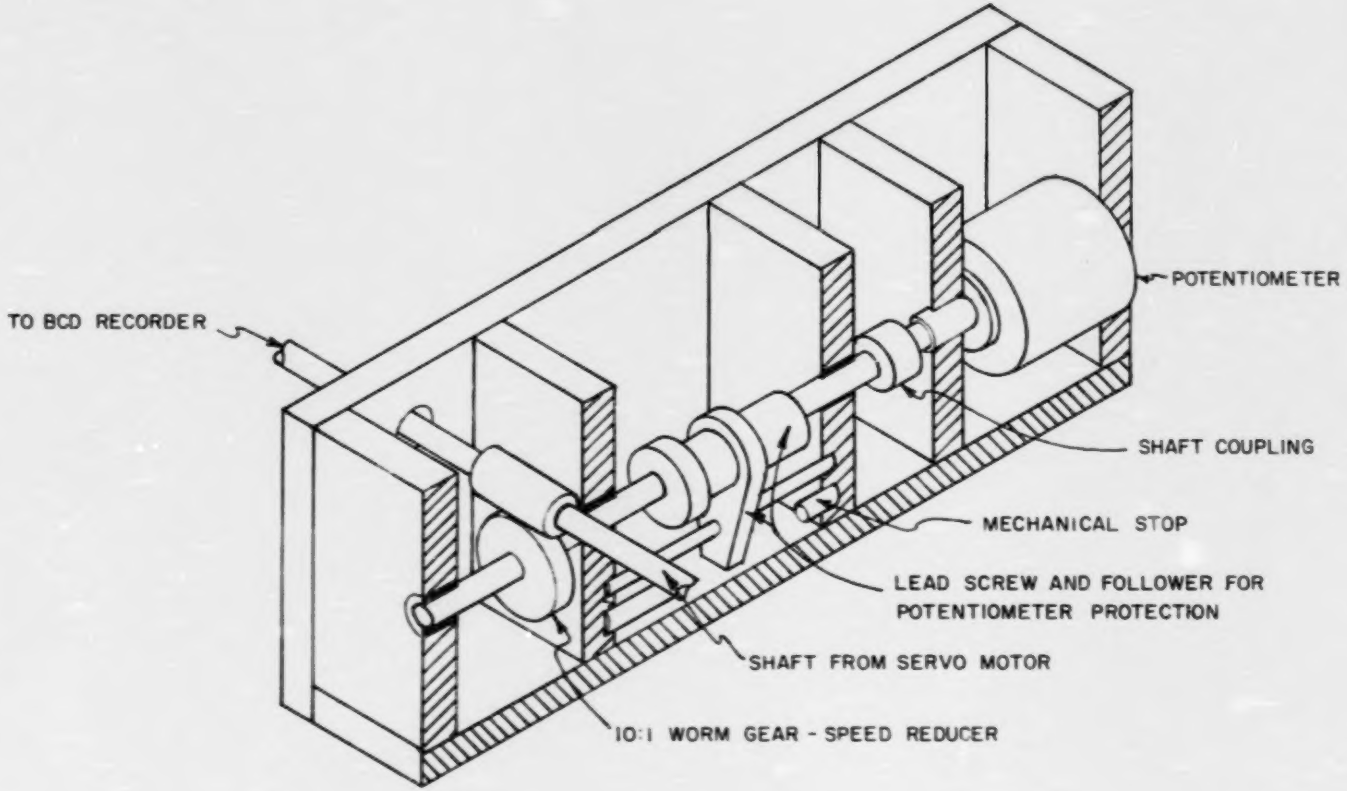
Figure 9. Modified Recorder


SERVO POT
RED
CLEAR
BLK
1
2
3
RED
GRN
BLK
CW
S
CCW
HELIPOT MODEL A
1012 Ω (NOMINAL 1K)
J102
P302
GND TO SHELL
NEU
FROM 115V, 60Hz
HOT
PUNCH CYCLE
MICRO SWITCH V3L-3-D8 (W/ROLLER)
BLK/WHT
HOT
BLK/WHT
VIO/WHT·HOT(SW)
VIO/WHT
BLU
TWPR
BLU
NEU
BLU
1μf
220
VAC
WHT
WHT
SERVO MTR
NOTE 1
PUNCH
MOTOR
CAPACITOR
4
5
BLK
BLK
PUNCH DRIVE MOTOR
YEL
YEL
RED
RED
RED
GRN
GRN
K301
(PUNCH)
TB 301
(NOTE 2)
C_M
NOTE 4
BLK
GRY
FROM SERVO AMP
TO TB402 (PROGRAMMER)

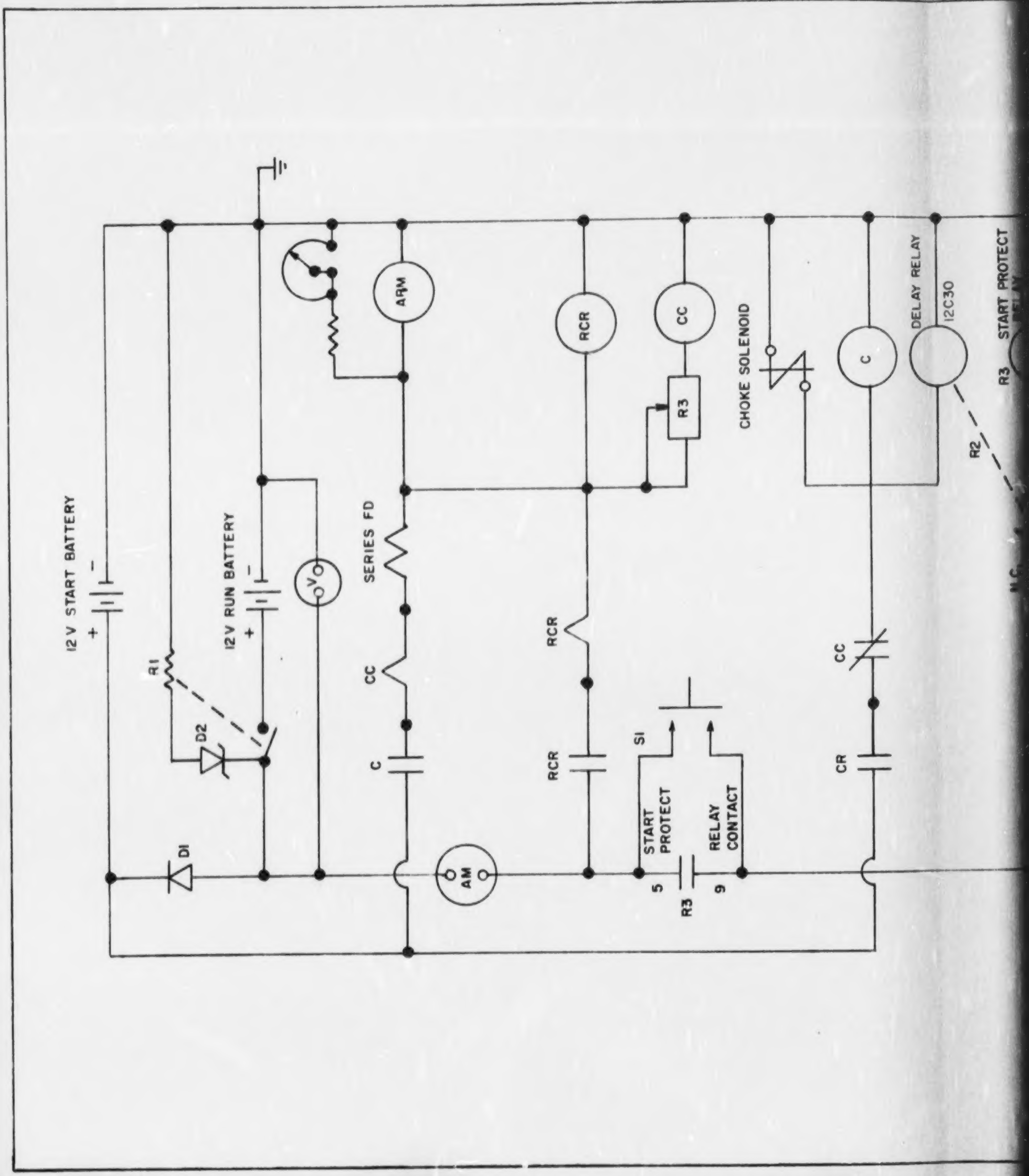
NOTES:

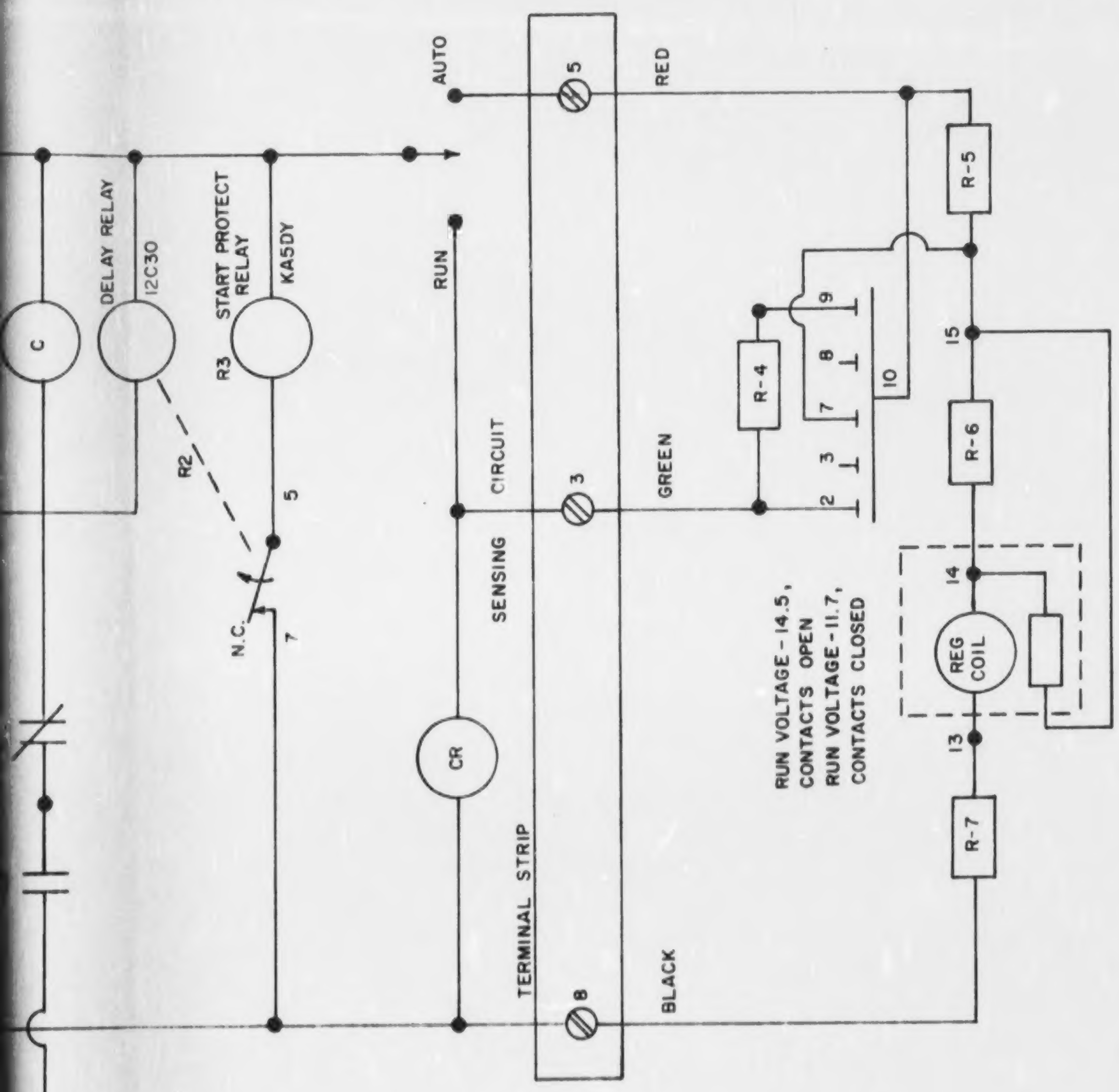
1. ROTATION FOR RECORDER DISCS IS UPSCALE (VIEWING RECORDER FRONT) SERVO POT IS CW AND SERVO MOTOR IS CCW
2. CONNECT 115V 60CPS TO TB301, 1 AND 3-CONNECT PUSH BUTTON PUNCH SW TO TB301, 1 AND 2
3. FLEX COUPLING (LOVEJOY A2-22) BETWEEN DRIVING SHAFT OF SERVO MOTOR BOX AND DRIVEN SHAFT OF RECORDER.
4. C_M MAY BE MALLORY PSU 12410, 124-140μf, AT 210 VAC

COMPLETED:	WARREN	RECORDER (300)
DATE:	1/5/66	
DRAWN:	MOAK	FIGURE 10A
DATE:	11/1/66	


TO BCD RECORDER
POTENTIOMETER
SHAFT COUPLING
MECHANICAL STOP
LEAD SCREW AND FOLLOWER FOR POTENTIOMETER PROTECTION
SHAFT FROM SERVO MOTOR
10:1 WORM GEAR - SPEED REDUCER

COMPLETED:	McLEOD	POTENTIOMETER DRIVE ASSEMBLY
DATE:	9/17/68	
DRAWN:	MOAK	FIGURE 10B
DATE:	9/23/68	

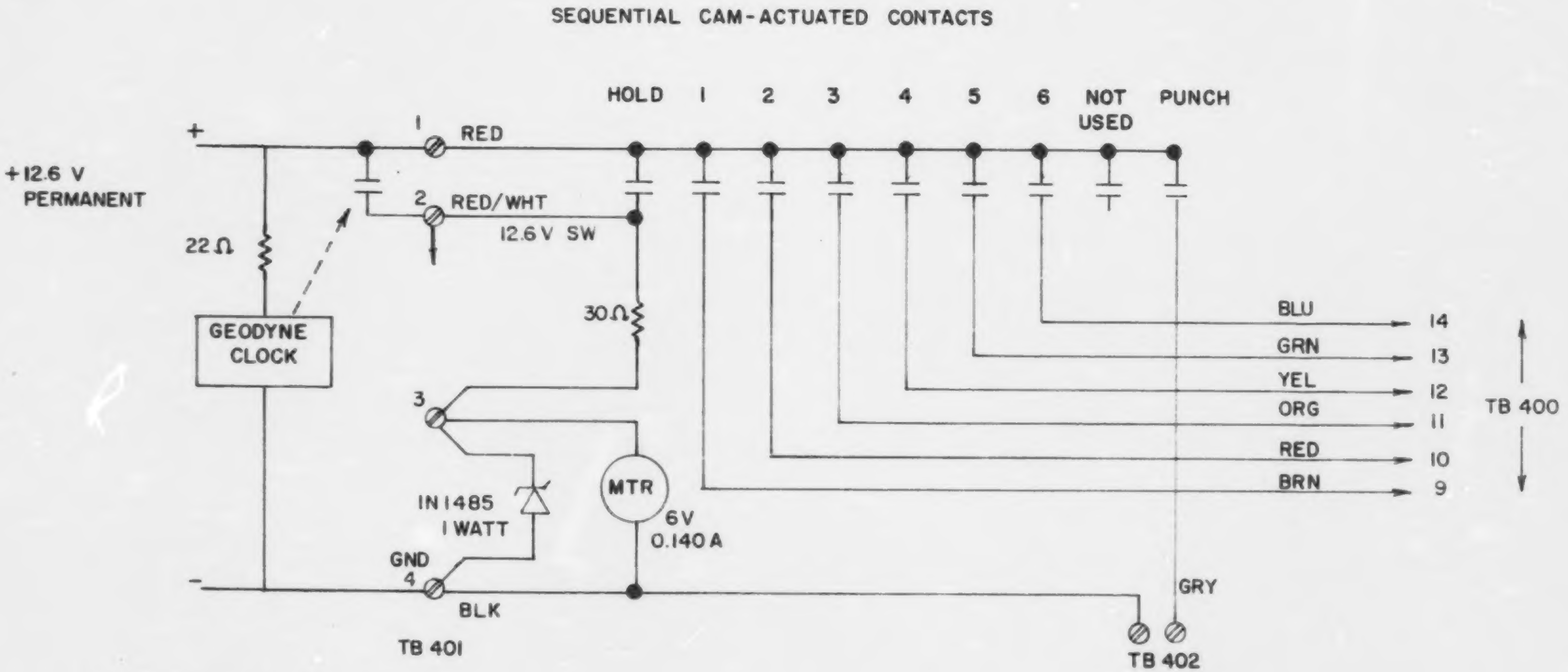

12 V START BATTERY
+
−
R1
D2
12 V RUN BATTERY
+
−
V
D1
SERIES FD
CC
C
ARM
AM
RCR
RCR
RCR
CC
R3
S1
START PROTECT
RELAY CONTACT
5
R3
9
CHOKE SOLENOID
C
CC
CR
DELAY RELAY
12C30
R2
START PROTECT
R3


AUTO
RUN
SENSING CIRCUIT
TERMINAL STRIP
5
3
8
RED
GREEN
BLACK
C
DELAY RELAY
12C30
START PROTECT RELAY
KA5DY
R3
R2
5
N.C.
7
CR
R-4
R-5
R-6
R-7
REG COIL
2
3
7
8
9
10
13
14
15
RUN VOLTAGE - 14.5,
CONTACTS OPEN
RUN VOLTAGE - 11.7,
CONTACTS CLOSED

COMPLETED: BERTHELOT
DATE: 6/18/68
DRAWN: MOAK
DATE: 10/12/68

CONTROLLER -
MOTOR GENERATOR

FIGURE 10C

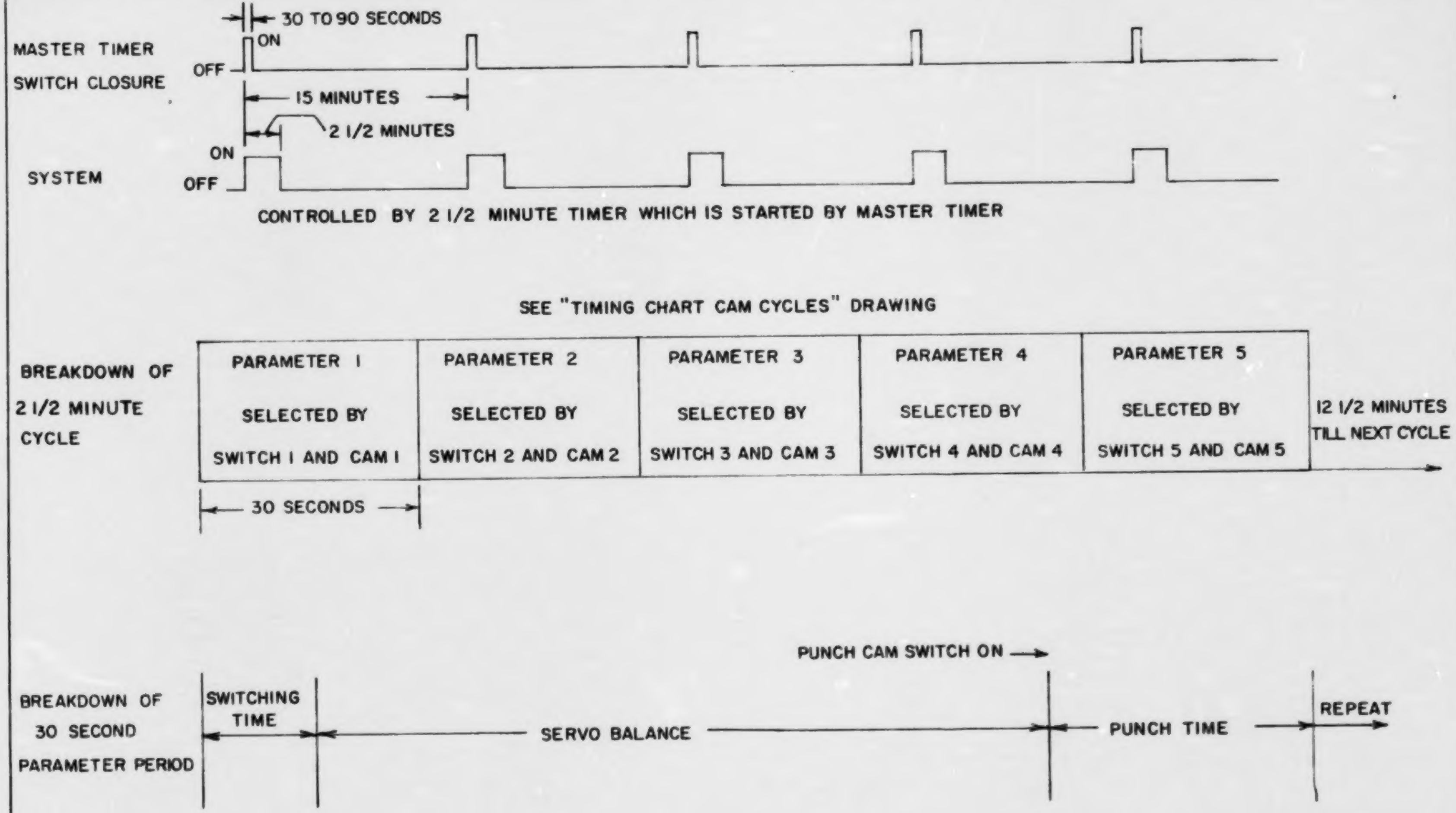

SEQUENTIAL CAM-ACTUATED CONTACTS
HOLD
1
2
3
4
5
6
NOT USED
PUNCH
+
+12.6 V PERMANENT
22Ω
GEODYNE CLOCK
1
RED
2
RED/WHT
12.6 V SW
30Ω
3
IN1485 1 WATT
MTR
6V 0.140 A
GND 4
BLK
−
TB 401
BLU
GRN
YEL
ORG
RED
BRN
14
13
12
11
10
9
TB 400
GRY
TB 402 TO K301

CLOCK IMPULSE DURATION: 80 SEC.

NOTE:

THE GEODYNE CLOCK SWITCH CLOSES FOR 80 SECONDS, DURING WHICH TIME THE CAM MOTOR CLOSES THE HOLD SWITCH. AFTER 2.5 MINUTES, THE HOLD SWITCH OPENS AND THE SEQUENCE ENDS. AFTER 12.5 MINUTES, THE CYCLE IS REPEATED.

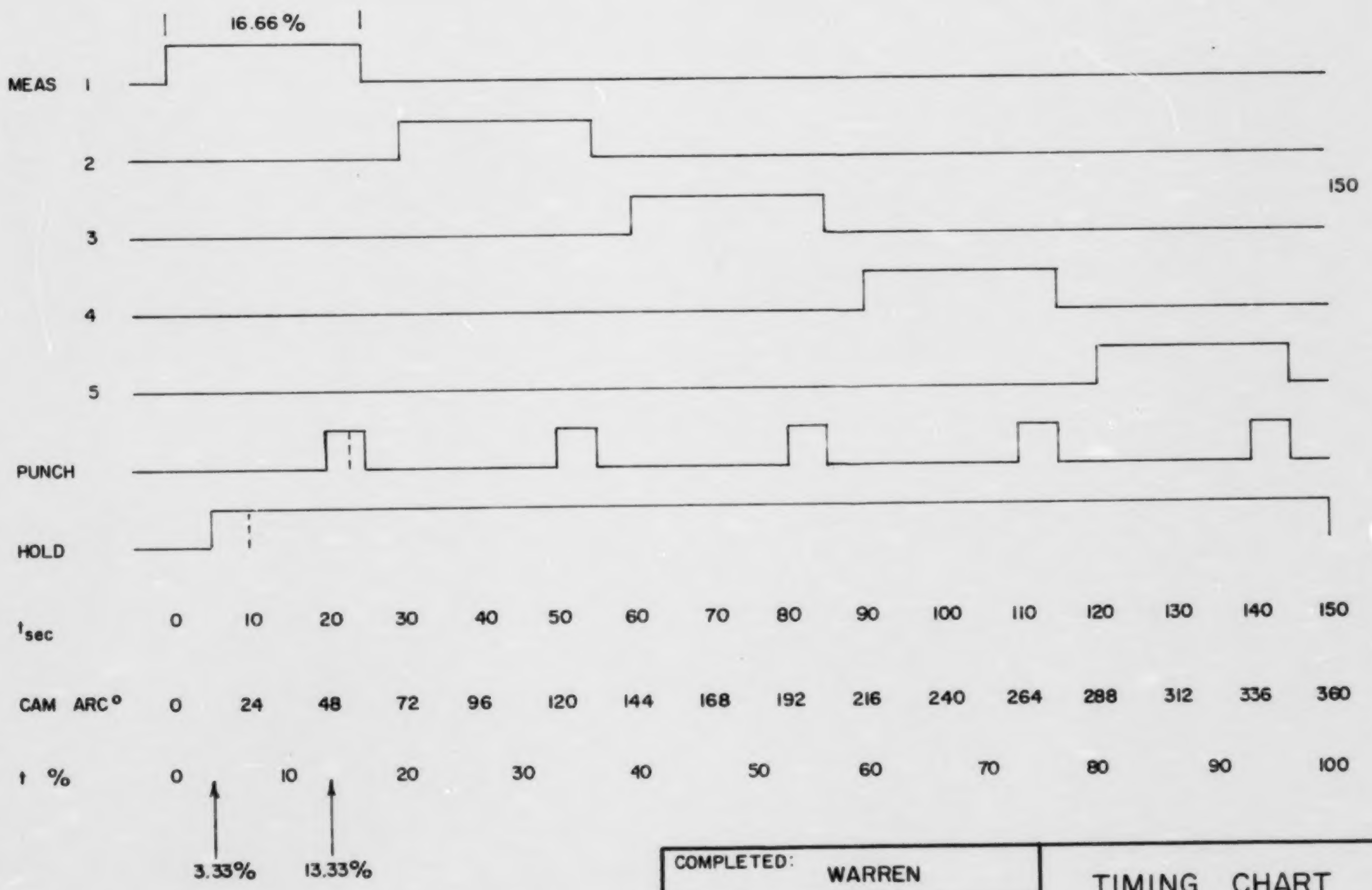
COMPLETED:	WARREN	PROGRAMMER (400)
DATE:	11/10/64	
DRAWN:	MOAK	FIGURE 11
DATE:	10/31/66	


30 TO 90 SECONDS
MASTER TIMER SWITCH CLOSURE
ON
OFF
15 MINUTES
2 1/2 MINUTES
SYSTEM
ON
OFF
CONTROLLED BY 2 1/2 MINUTE TIMER WHICH IS STARTED BY MASTER TIMER
SEE "TIMING CHART CAM CYCLES" DRAWING
BREAKDOWN OF 2 1/2 MINUTE CYCLE
PARAMETER 1 SELECTED BY SWITCH 1 AND CAM 1
PARAMETER 2 SELECTED BY SWITCH 2 AND CAM 2
PARAMETER 3 SELECTED BY SWITCH 3 AND CAM 3
PARAMETER 4 SELECTED BY SWITCH 4 AND CAM 4
PARAMETER 5 SELECTED BY SWITCH 5 AND CAM 5
12 1/2 MINUTES TILL NEXT CYCLE
30 SECONDS
PUNCH CAM SWITCH ON
BREAKDOWN OF 30 SECOND PARAMETER PERIOD
SWITCHING TIME
SERVO BALANCE
PUNCH TIME
REPEAT

NOTES:

1. D.O. IF MEASURED IS PARAMETER 5, TO ALLOW D.O. STIRRING MOTOR TIME TO AERATE CELL. D.O. MOTOR IS ON FULL 2 1/2 MINUTES.

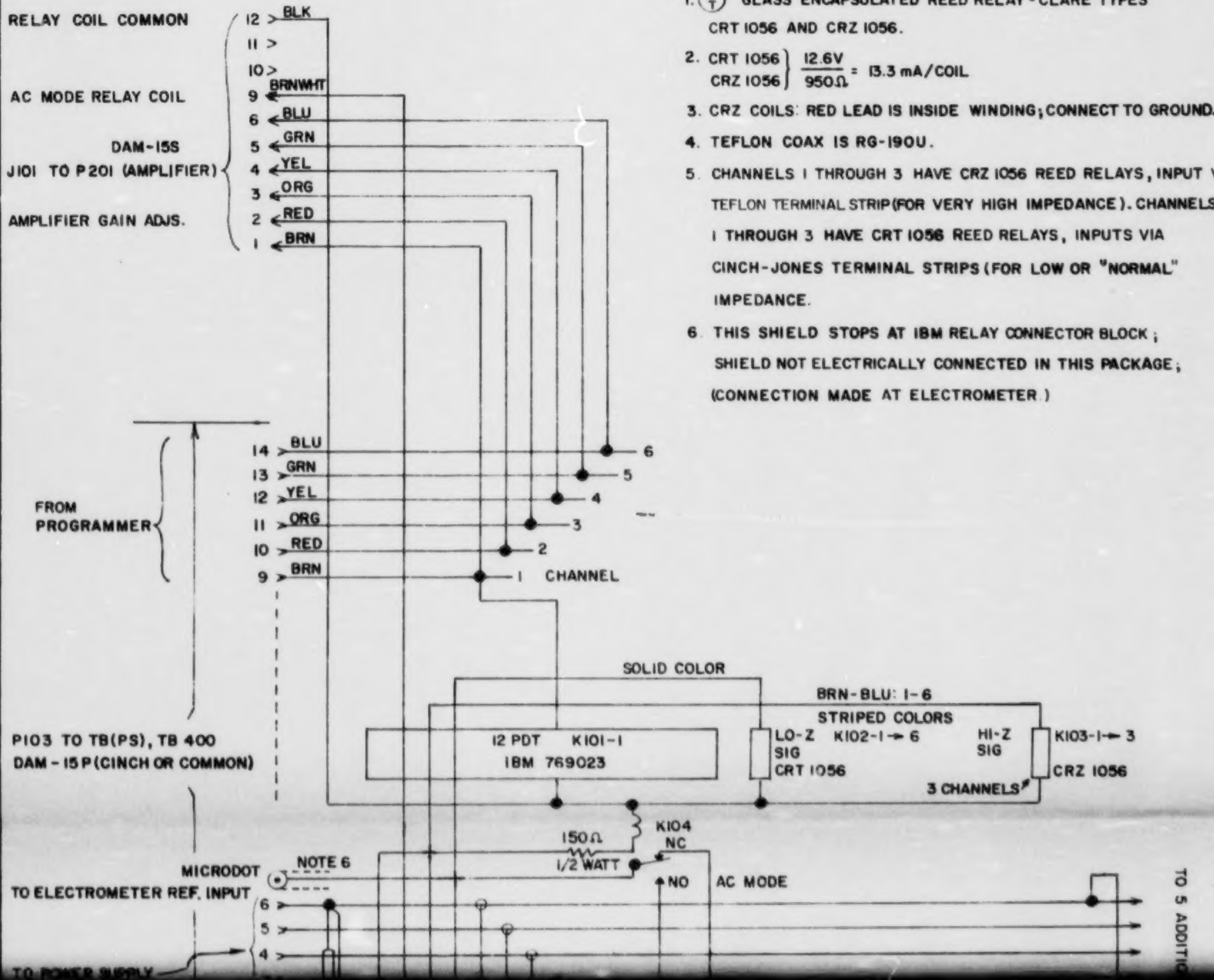
COMPLETED:	RAIBLE	TIMING SEQUENCE
DATE:	9/5/65	
DRAWN:	MOAK	FIGURE 12
DATE:	11/4/66	



COMPLETED:	WARREN
DATE:	2/21/63
DRAWN:	MOAK
DATE:	11/1/66

TIMING CHART
CAM CYCLES

FIGURE 13


RELAY COIL COMMON
AC MODE RELAY COIL
DAM-15S
J101 TO P201 (AMPLIFIER)
AMPLIFIER GAIN ADJS.
12 > BLK
11 >
10 >
9 BRNWHT
6 BLU
5 GRN
4 YEL
3 ORG
2 RED
1 BRN
FROM PROGRAMMER
14 > BLU
13 > GRN
12 > YEL
11 > ORG
10 > RED
9 > BRN
6
5
4
3
2
1 CHANNEL
SOLID COLOR
BRN-BLU: 1-6
STRIPED COLORS
P103 TO TB(PS), TB 400
DAM-15P (CINCH OR COMMON)
12 PDT K101-1
IBM 769023
LO-Z SIG CRT 1056
K102-1 → 6
HI-Z SIG
K103-1 → 3
CRZ 1056
3 CHANNELS
150 Ω
1/2 WATT
K104
NC
NO
AC MODE
MICRODOT
NOTE 6
TO ELECTROMETER REF. INPUT
6 >
5 >
4 >
TO POWER SUPPLY
TO 5 ADDITIO

NOTES:

1. (⏚) GLASS ENCAPSULATED REED RELAY - CLARE TYPES CRT 1056 AND CRZ 1056.

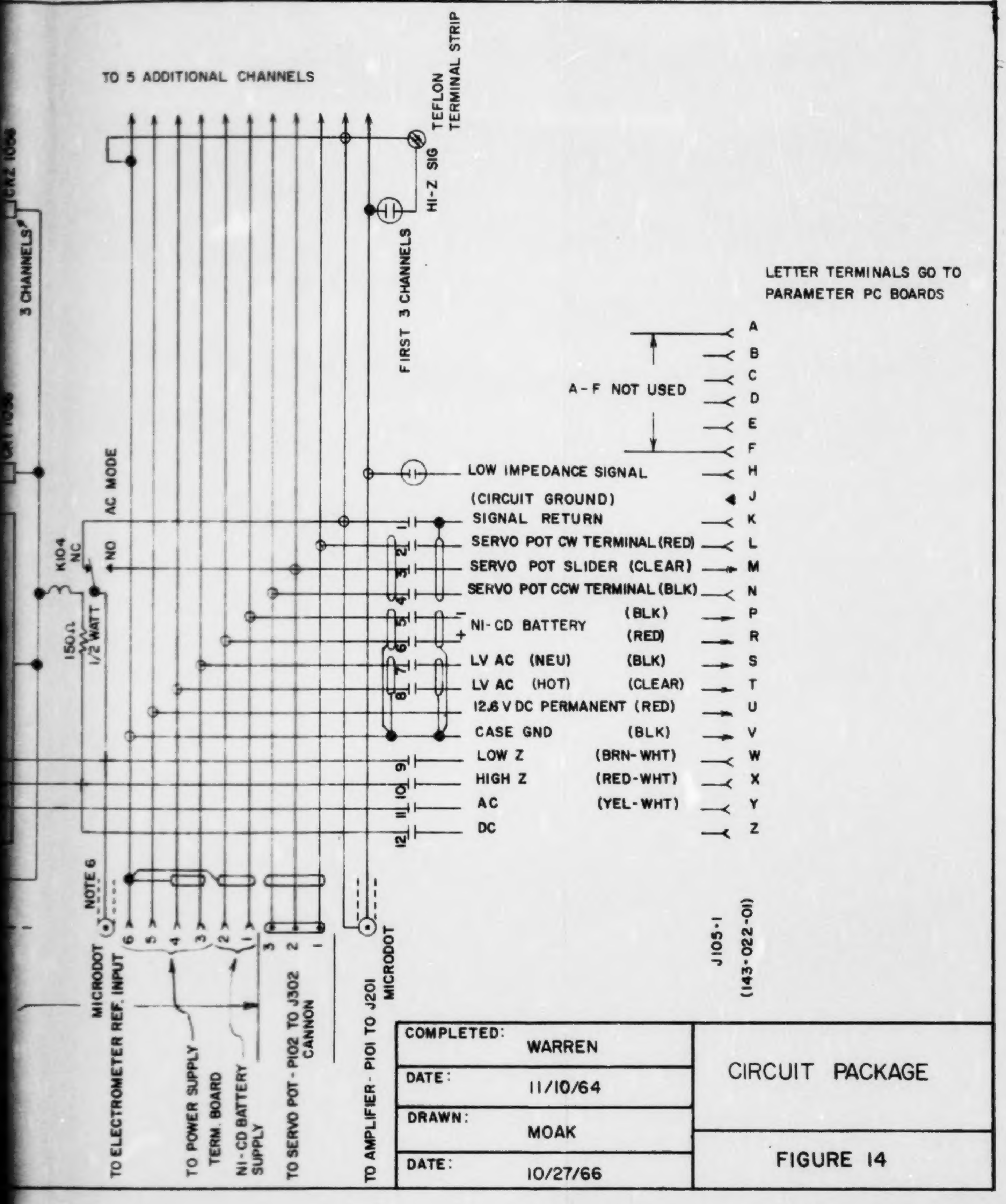
2. $\left.\begin{array}{l}\text{CRT 1056}\\ \text{CRZ 1056}\end{array}\right\}\ \frac{12.6\text{V}}{950\Omega} = 13.3\text{ mA/COIL}$

3. CRZ COILS: RED LEAD IS INSIDE WINDING; CONNECT TO GROUND.

4. TEFLON COAX IS RG-190U.

5. CHANNELS 1 THROUGH 3 HAVE CRZ 1056 REED RELAYS, INPUT VIA TEFLON TERMINAL STRIP (FOR VERY HIGH IMPEDANCE). CHANNELS 1 THROUGH 3 HAVE CRT 1056 REED RELAYS, INPUTS VIA CINCH-JONES TERMINAL STRIPS (FOR LOW OR "NORMAL" IMPEDANCE.

6. THIS SHIELD STOPS AT IBM RELAY CONNECTOR BLOCK; SHIELD NOT ELECTRICALLY CONNECTED IN THIS PACKAGE; (CONNECTION MADE AT ELECTROMETER.)


TO 5 ADDITIONAL CHANNELS
TEFLON TERMINAL STRIP
HI-Z SIG
FIRST 3 CHANNELS
3 CHANNELS*
CR2 1038
CR1 1038
AC MODE
K104
NC
NO
150Ω
1/2 WATT
LETTER TERMINALS GO TO PARAMETER PC BOARDS
A-F NOT USED
A
B
C
D
E
F
LOW IMPEDANCE SIGNAL
H
(CIRCUIT GROUND)
J
SIGNAL RETURN
K
SERVO POT CW TERMINAL (RED)
L
SERVO POT SLIDER (CLEAR)
M
SERVO POT CCW TERMINAL (BLK)
N
NI-CD BATTERY
(BLK)
P
(RED)
R
LV AC (NEU) (BLK)
S
LV AC (HOT) (CLEAR)
T
12.6 V DC PERMANENT (RED)
U
CASE GND (BLK)
V
LOW Z (BRN-WHT)
W
HIGH Z (RED-WHT)
X
AC (YEL-WHT)
Y
DC
Z
1
2
3
4
5
6
7
8
9
10
11
12
-
+
NOTE 6
J105-1
(143-022-01)
6
5
4
3
2
1
3
2
1
MICRODOT
TO ELECTROMETER REF. INPUT
TO POWER SUPPLY TERM. BOARD
NI-CD BATTERY SUPPLY
TO SERVO POT - P102 TO J302 CANNON
TO AMPLIFIER - P101 TO J201 MICRODOT

COMPLETED: WARREN

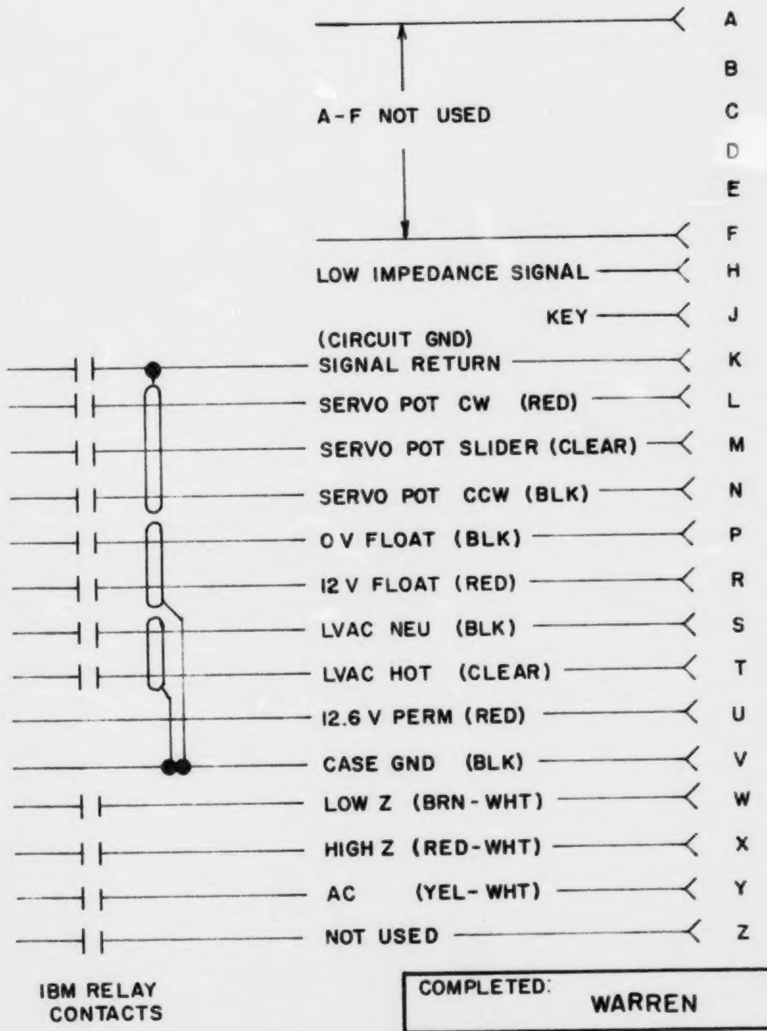
DATE: 11/10/64

DRAWN: MOAK

DATE: 10/27/66

CIRCUIT PACKAGE

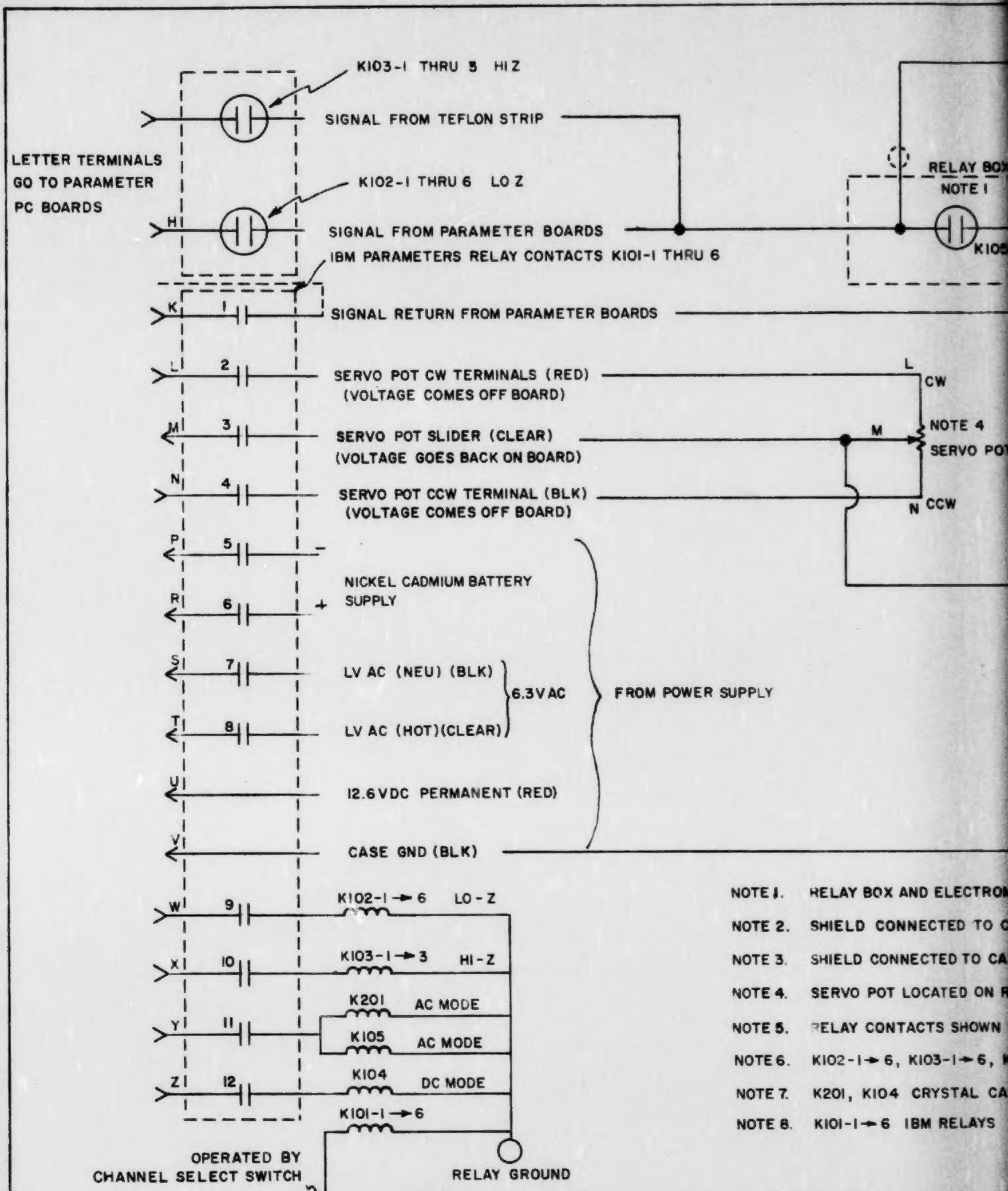
FIGURE 14


A
B
C
D
E
F
A-F NOT USED
LOW IMPEDANCE SIGNAL
H
KEY
J
(CIRCUIT GND)
SIGNAL RETURN
K
SERVO POT CW (RED)
L
SERVO POT SLIDER (CLEAR)
M
SERVO POT CCW (BLK)
N
O V FLOAT (BLK)
P
12 V FLOAT (RED)
R
LVAC NEU (BLK)
S
LVAC HOT (CLEAR)
T
12.6 V PERM (RED)
U
CASE GND (BLK)
V
LOW Z (BRN-WHT)
W
HIGH Z (RED-WHT)
X
AC (YEL-WHT)
Y
NOT USED
Z
IBM RELAY
CONTACTS

COMPLETED:	WARREN
DATE:	12/4/64
DRAWN:	MOAK
DATE:	10/27/66

CIRCUIT BOARD RECEPTACLES PIN COMMITMENTS

FIGURE 15


K103-1 THRU 3 HI Z
SIGNAL FROM TEFLON STRIP
LETTER TERMINALS GO TO PARAMETER PC BOARDS
K102-1 THRU 6 LO Z
H
SIGNAL FROM PARAMETER BOARDS
IBM PARAMETERS RELAY CONTACTS K101-1 THRU 6
RELAY BOX
NOTE 1
K105
K
1
SIGNAL RETURN FROM PARAMETER BOARDS
L
2
SERVO POT CW TERMINALS (RED)
(VOLTAGE COMES OFF BOARD)
CW
M
3
SERVO POT SLIDER (CLEAR)
(VOLTAGE GOES BACK ON BOARD)
NOTE 4
SERVO POT
N
4
SERVO POT CCW TERMINAL (BLK)
(VOLTAGE COMES OFF BOARD)
CCW
P
5
-
NICKEL CADMIUM BATTERY SUPPLY
R
6
+
S
7
LV AC (NEU) (BLK)
6.3 V AC
FROM POWER SUPPLY
T
8
LV AC (HOT)(CLEAR)
U
12.6 VDC PERMANENT (RED)
V
CASE GND (BLK)
W
9
K102-1 → 6
LO - Z
X
10
K103-1 → 3
HI - Z
Y
11
K201
AC MODE
K105
AC MODE
Z
12
K104
DC MODE
K101-1 → 6
OPERATED BY CHANNEL SELECT SWITCH
RELAY GROUND

NOTE 1. RELAY BOX AND ELECTRON

NOTE 2. SHIELD CONNECTED TO C

NOTE 3. SHIELD CONNECTED TO CA

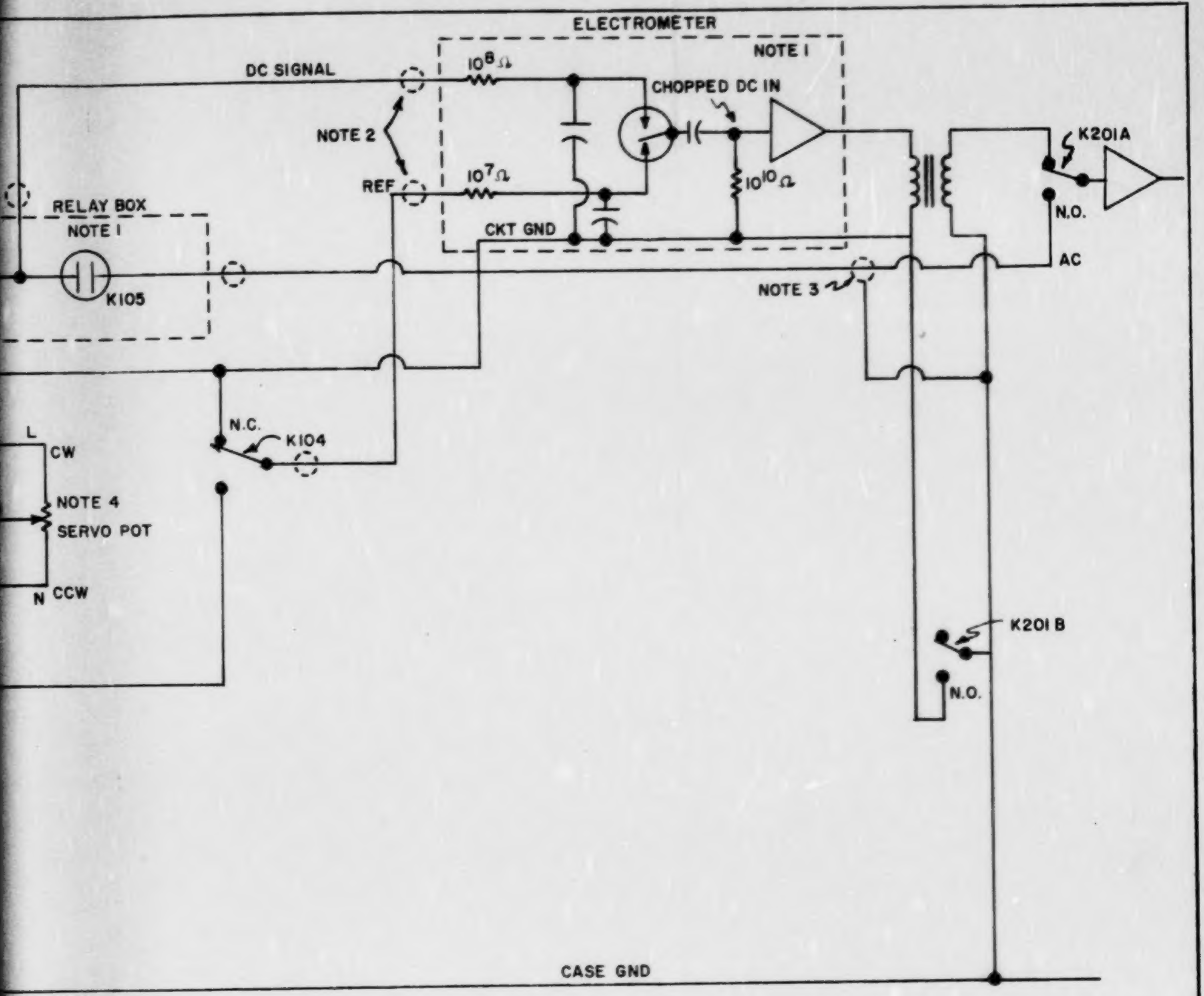
NOTE 4. SERVO POT LOCATED ON R

NOTE 5. RELAY CONTACTS SHOWN

NOTE 6. K102-1 → 6, K103-1 → 6, K

NOTE 7. K201, K104 CRYSTAL CA

NOTE 8. K101-1 → 6 IBM RELAYS


ELECTROMETER
NOTE 1
DC SIGNAL
$10^8 \Omega$
CHOPPED DC IN
NOTE 2
REF
$10^7 \Omega$
$10^{10} \Omega$
CKT GND
K201A
N.O.
AC
RELAY BOX
NOTE 1
K105
NOTE 3
N.C.
K104
L
CW
NOTE 4
SERVO POT
N
CCW
K201 B
N.O.
CASE GND

X AND ELECTROMETER BOX ARE AT CIRCUIT GROUND

CONNECTED TO CIRCUIT GROUND

ONNECTED TO CASE GROUND

T LOCATED ON RECORDER

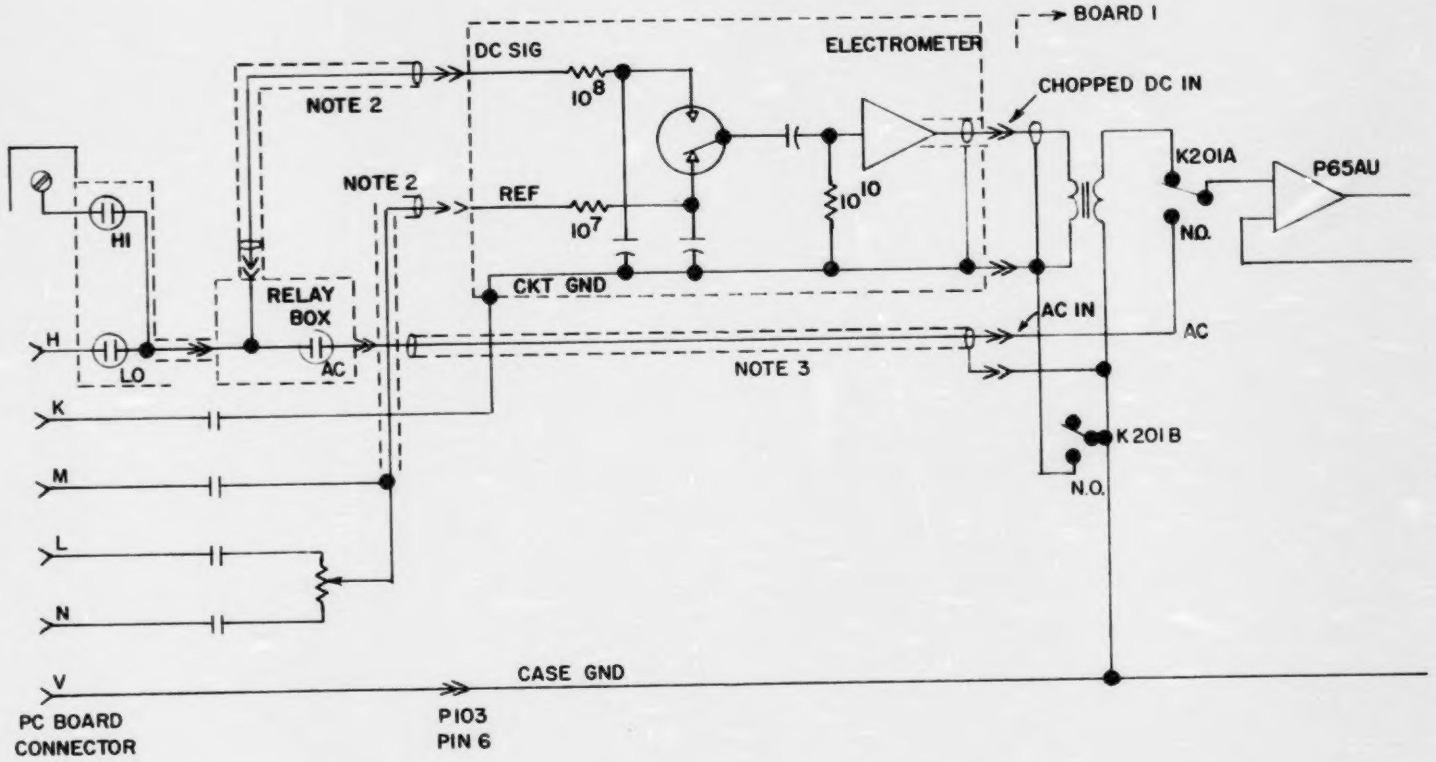
NTACTS SHOWN WITH COILS NON-ENERGIZED

6, K103-1→6, K105 REED RELAYS

04 CRYSTAL CAN RELAYS

IBM RELAYS

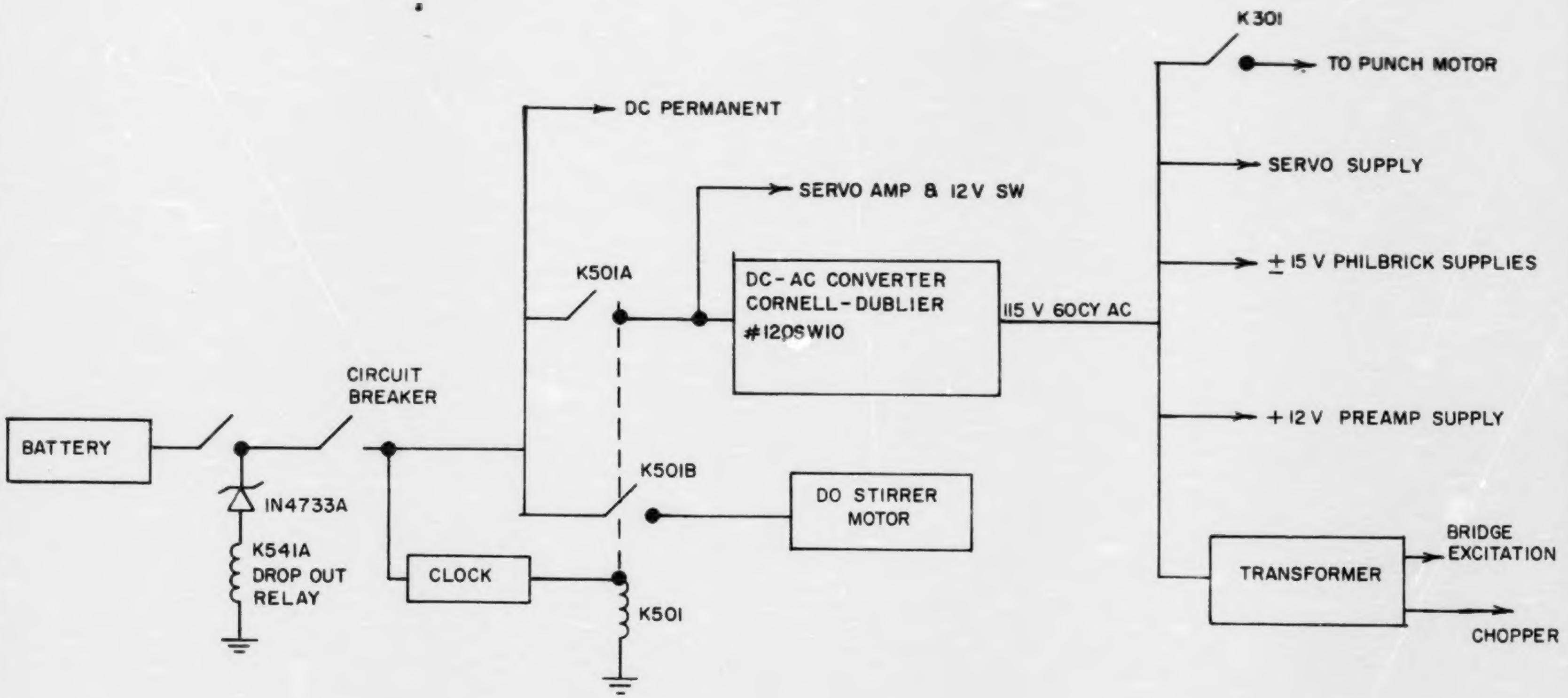
COMPLETED:	BERTHELOT	SIGNAL PATH DIAGRAM
DATE:	12/7/67	
DRAWN:	MOAK	FIGURE 16
DATE:	12/8/67	


BOARD I
ELECTROMETER
DC SIG
10^8
NOTE 2
CHOPPED DC IN
K201A
P65AU
N.O.
HI
NOTE 2
REF
10^7
10^{10}
RELAY BOX
CKT GND
H
LO
AC
AC IN
AC
NOTE 3
K
K201B
N.O.
M
L
N
V
CASE GND
PC BOARD CONNECTOR
P103
PIN 6

NOTES:

1. RELAY BOX AND ELECTROMETER BOX ARE AT CIRCUIT GROUND
2. SHIELD CONNECTED TO CIRCUIT GROUND.
3. SHIELD CONNECTED TO CASE GROUND.
4. K201 COIL ENERGIZED FOR AC MODE.

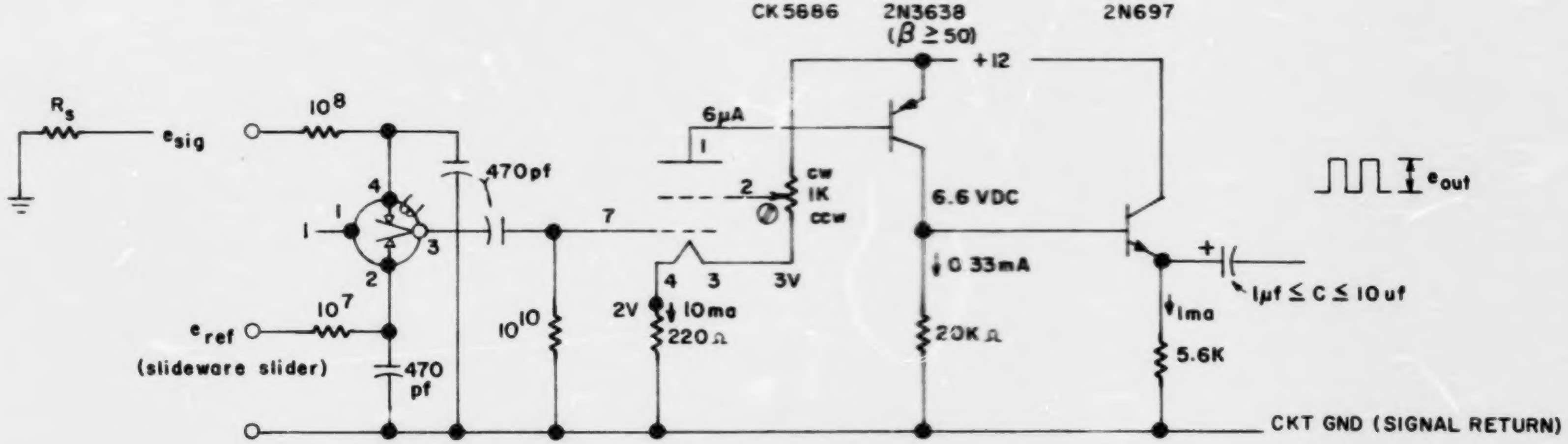
COMPLETED:	WARREN	PROGRAMMED SWITCHING INPUTS
DATE:	2/25/66	
DRAWN:	MOAK	FIGURE 17
DATE:	11/2/66	


K301
TO PUNCH MOTOR
DC PERMANENT
SERVO SUPPLY
SERVO AMP & 12V SW
K501A
DC-AC CONVERTER
CORNELL-DUBLIER
#120SW10
115 V 60CY AC
± 15 V PHILBRICK SUPPLIES
CIRCUIT
BREAKER
BATTERY
+ 12 V PREAMP SUPPLY
K501B
DO STIRRER
MOTOR
IN4733A
K541A
DROP OUT
RELAY
CLOCK
K501
TRANSFORMER
BRIDGE
EXCITATION
CHOPPER

NOTES:

1. RELAY CONTACTS K541A MUST BE CLOSED MANUALLY TO ENERGIZE RELAY COIL K541.

COMPLETED:	RAIBLE	PRIMARY POWER DISTRIBUTION
DATE:	11/25/68	
DRAWN:	MOAK	FIGURE 18
DATE:	12/17/68	


CK5886
2N3638
($\beta \geq 50$)
2N697
R_s
e_{sig}
10^8
470pf
+12
6μA
1
2
cw
1K
ccw
4
1
3
2
7
6.6 VDC
e_{out}
0.33mA
10^7
e_{ref}
(slideware slider)
470 pf
10^{10}
2V
10ma
220Ω
4
3
3V
20KΩ
Ima
5.6K
$1\mu f \leq C \leq 10uf$
CKT GND (SIGNAL RETURN)

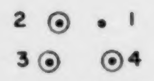
NOTES:

1. WHEN CONNECTED TO INPUT TRANSFORMER OF FOLLOWING STAGE (BOARD 1) GAIN TO APPROXIMATELY 50 FOR 1MVDC TO e_{sig} TERMINAL; REFERENCE TERMINAL CONNECTED TO FIRST GRID. 0.05 CAPACITOR ACROSS SECONDARY OF INPUT TRANSFORMER ON BOARD 1 REDUCES THIS GAIN TO APPROXIMATELY 40.
2. ALL 470pf ARE CORNING GLASS WORKS' DIELECTRIC CAPACITORS
3. WHEN CHOPPER COIL IS DE-ENERGIZED, CHOPPER ARMATURE (3) RESTS ON CONTACT (4)
4. FOR e_{ref} = 10mV AND e_{sig} = 0V:

R	e_{out} pk-pk mV
0	160
100 meg	144

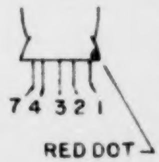
R_s SIMULATING ELECTRODE SOURCE RESISTANCE

DRIVE COIL: 6.3vac



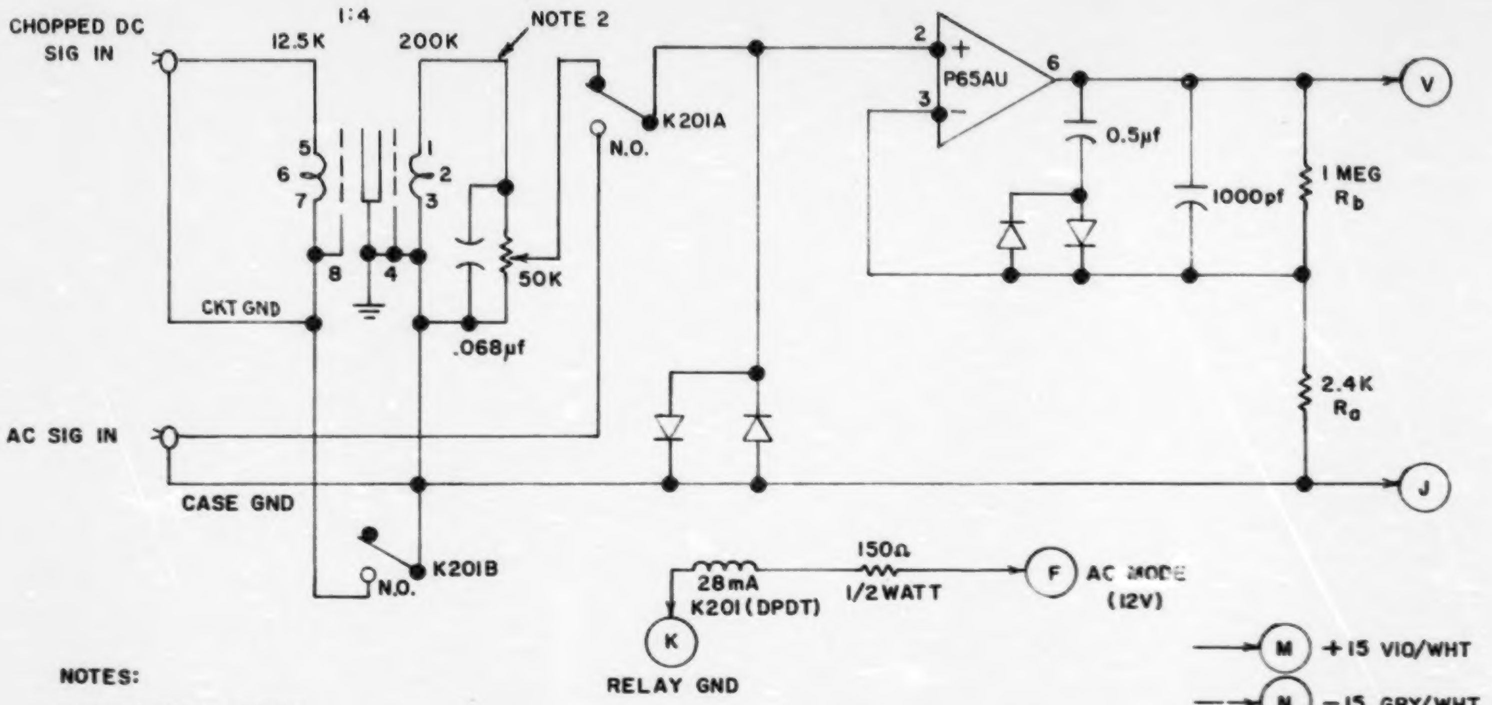
BRISTOL SYNCHROVERTER
SWITCH-PART NO: C1407-3

CK5886


7 4 3 2 1
RED DOT

TUBE HEADS	TO PIN, 7 PIN HEADER (COUNTING CW FROM BOTTOM)
1. PLATE	→ 1
2. SCREEN	→ 3
3. FIL +	→ 5
4. FIL −	→ 7
7. GRID	

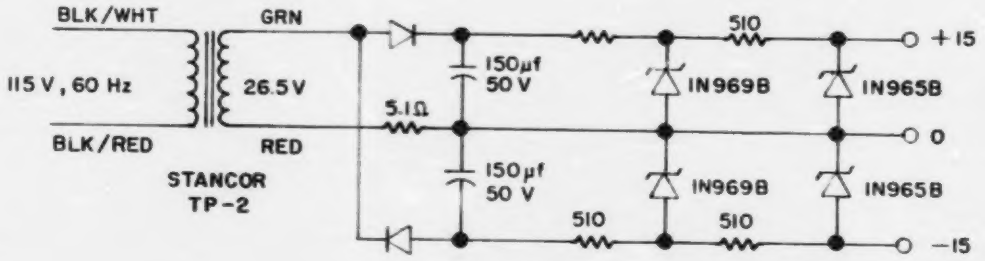
COMPLETED: WARREN	ELECTROMETER INPUT AMPLIFIER
DATE: 11/17/65	
DRAWN: MOAK	
DATE: 9/27/66	FIGURE 19


CHOPPED DC SIG IN
12.5K
1:4
200K
NOTE 2
5
6
7
1
2
3
8
4
CKT GND
.068µf
50K
K201A
N.O.
2
3
+
−
P65AU
6
0.5µf
1000pf
1 MEG
R_b
2.4K
R_a
V
J
AC SIG IN
CASE GND
K201B
N.O.
28mA
K201 (DPDT)
150Ω
1/2 WATT
F
AC MODE
(12V)
K
RELAY GND
M
+15 VIO/WHT
N
−15 GRY/WHT
KEY
E

NOTES:

1. ALL DIODES: IN4154
2. Z ≈ 15K TO 20K LOOKING BACK INTO ELECTROMETER (FROM TRANSFORMER SECONDARY) AS DETERMINED BY 1/2 VOLTAGE METHOD WITH UNITY VOLTAGE = 40mV. (THIS VALUE DOES NOT INCLUDE 50KΩ POT ACROSS TRANSFORMER SECONDARY.)
3. VOLTAGE GAIN = $\frac{31 \text{mV rms}}{0.1 \text{mV rms}} = 310$

COMPLETED: WARREN	SERVO AMPLIFIER BOARD I
DATE: 12/5/65	
DRAWN: MOAK	FIGURE 20
DATE: 9/14/66	

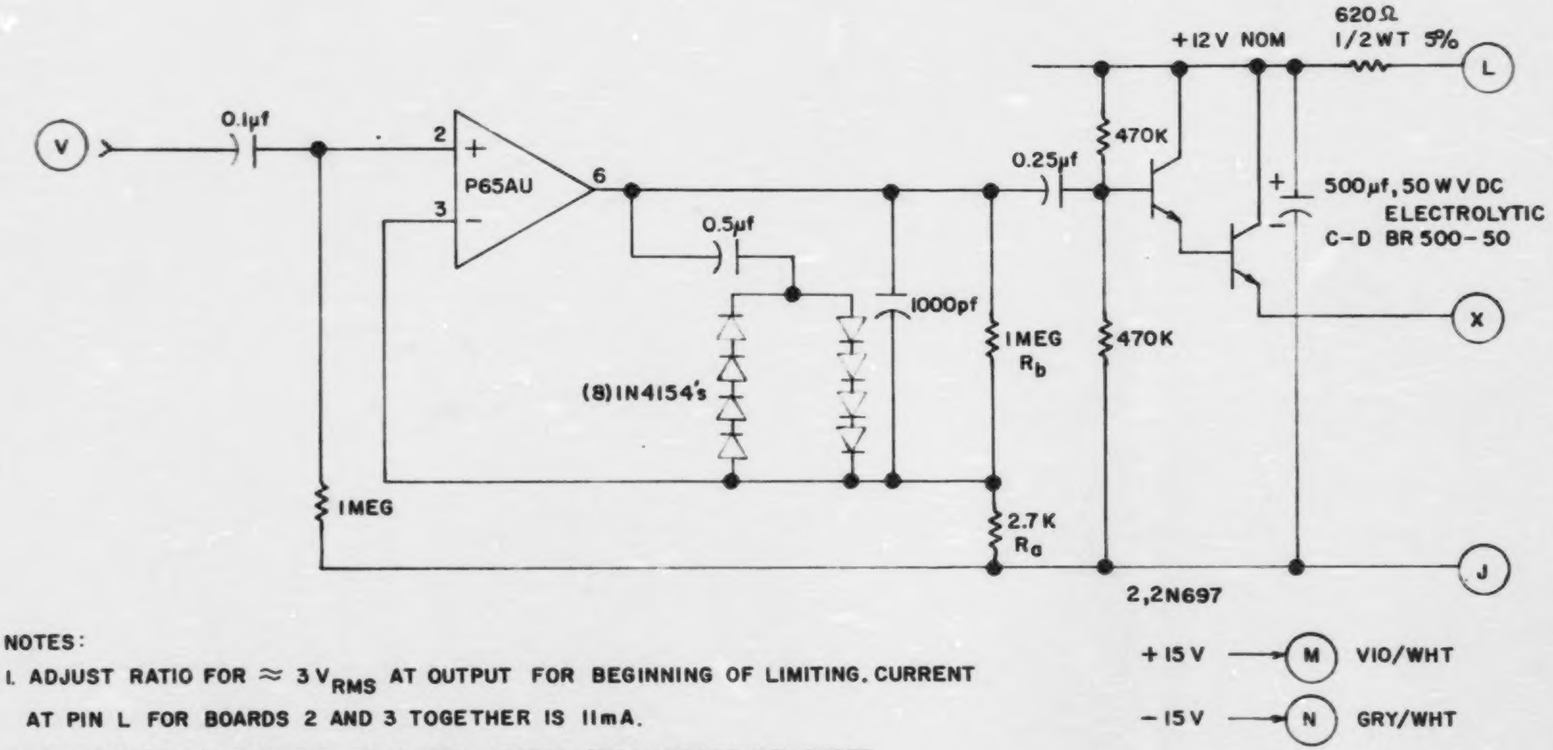

BLK/WHT
115 V, 60 Hz
BLK/RED
STANCOR
TP-2
GRN
26.5 V
RED
5.1Ω
150μf
50 V
150μf
50 V
510
510
510
IN969B
IN969B
IN965B
IN965B
+15
0
−15

5%, 1 WATT RESISTORS

COMPLETED:	WARREN
DATE:	6/1/65
DRAWN:	MOAK
DATE:	10/31/66

POWER SUPPLY FOR PHILBRICK AMPLIFIERS

FIGURE 21


V
0.1µf
2
3
+
−
P65AU
6
0.5µf
1000pf
(8) 1N4154's
1MEG
1MEG
R_b
2.7K
R_a
0.25µf
470K
470K
+12 V NOM
620Ω
1/2 WT 5%
L
+
−
500µf, 50 W V DC
ELECTROLYTIC
C-D BR 500-50
X
J
2,2N697
+15 V
M
VIO/WHT
−15 V
N
GRY/WHT

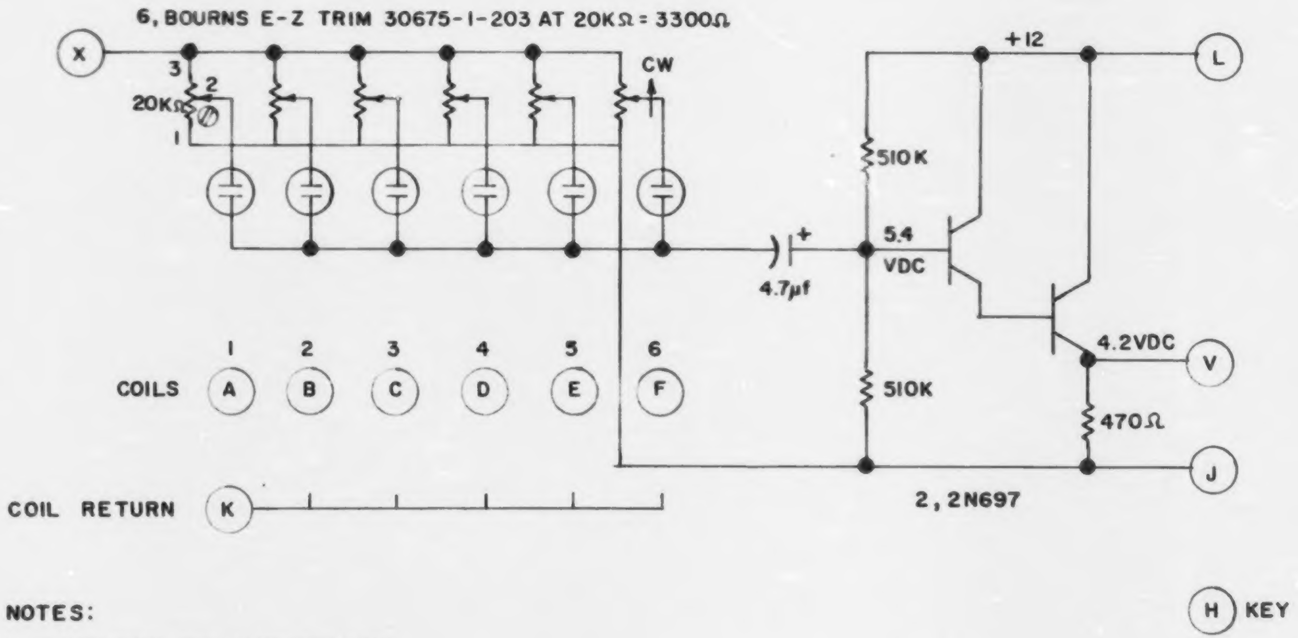
NOTES:

1. ADJUST RATIO FOR ≈ 3 V_{RMS} AT OUTPUT FOR BEGINNING OF LIMITING. CURRENT AT PIN L FOR BOARDS 2 AND 3 TOGETHER IS 11mA.

2. GAIN, BOARD 1 X BOARD 2 = 310 X 350 = 108500. (EACH BOARD MEASURED INDEPENDENTLY WITH e_m CHOSEN TO MINIMIZE CLIPPING.)

3. VOLTAGE GAIN = $\frac{35\,mVrms}{0.1\,mVrms}$ = 350

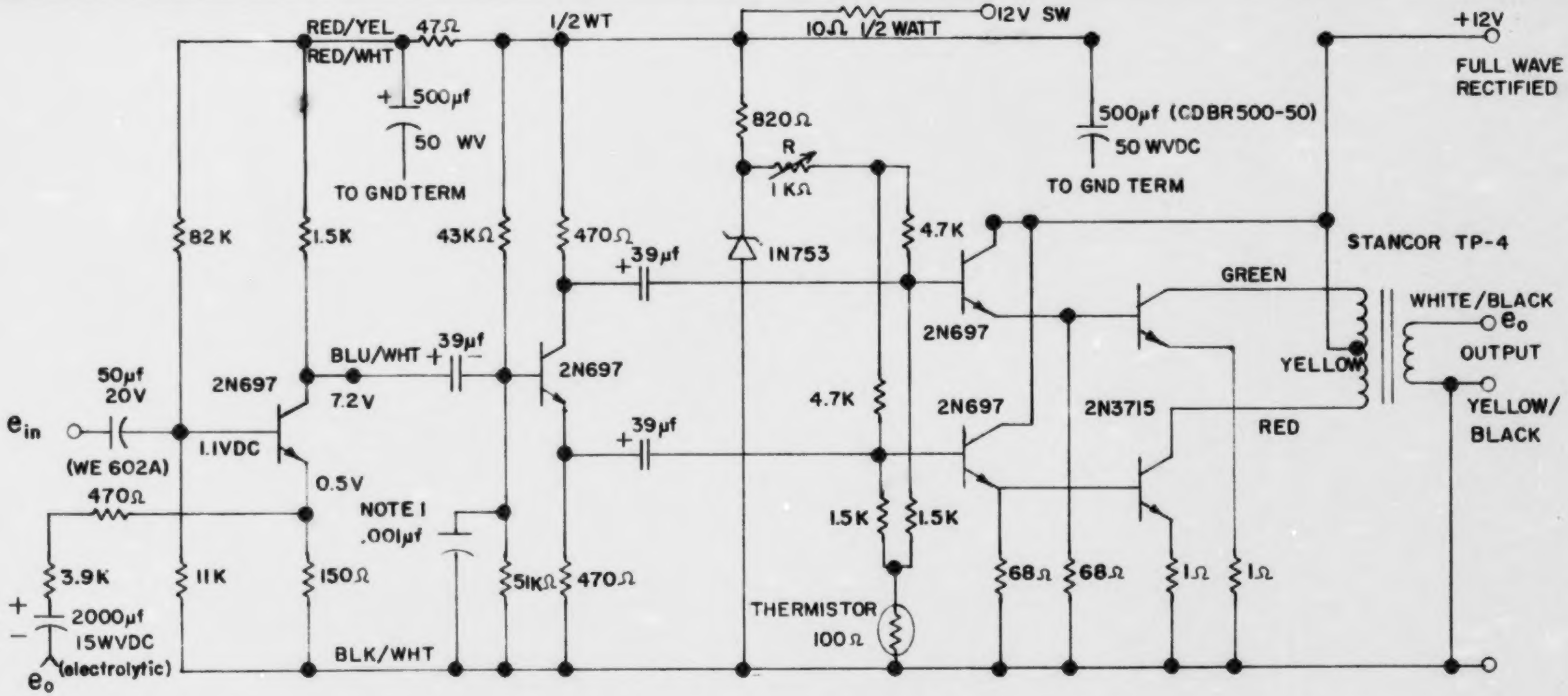
COMPLETED:	WARREN	SERVO AMPLIFIER BOARD 2
DATE:	12/15/65	
DRAWN:	MOAK	FIGURE 22
DATE:	9/17/66	


6, BOURNS E-Z TRIM 30675-1-203 AT 20KΩ = 3300Ω
X
3
2
20KΩ
1
CW
+12
L
510K
5.4
VDC
4.7µf
4.2VDC
V
510K
470Ω
J
2, 2N697
1
2
3
4
5
6
COILS
A
B
C
D
E
F
COIL RETURN
K
H
KEY

NOTES:

1. CLOCKWISE FOR MAXIMUM GAIN
2. (N) DESIGNATES PINS ON P.C. BOARD CONNECTOR
3. ⏀ DESIGNATES CLARE CRT-1056 REED RELAY

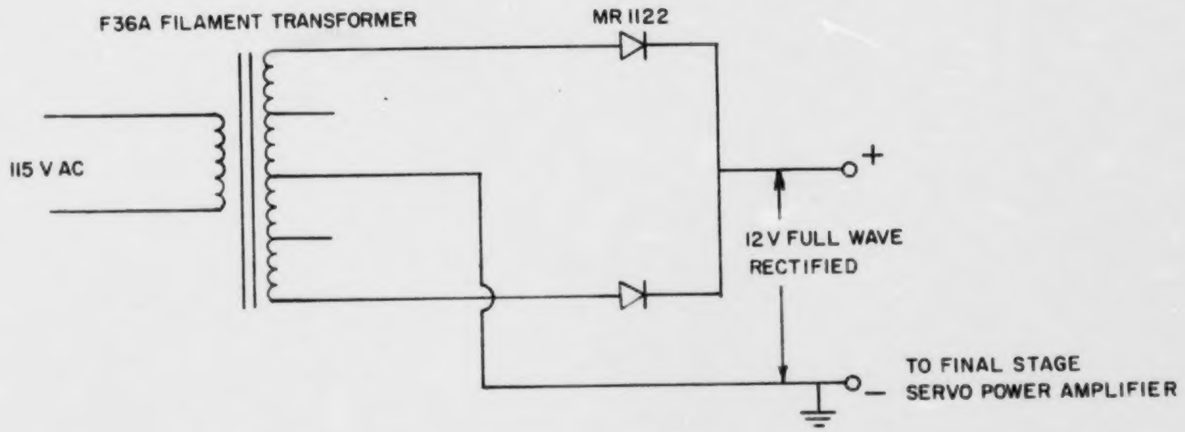
COMPLETED:	WARREN	SERVO AMPLIFIER BOARD 3 (CHANNEL GAIN ADJUST)
DATE:	8/7/65	
DRAWN:	MOAK	FIGURE 23
DATE:	9/17/66	


RED/YEL
47Ω
RED/WHT
+ 500μf
50 WV
TO GND TERM
1/2 WT
10Ω 1/2 WATT
12V SW
+12V
FULL WAVE RECTIFIED
820Ω
R
1KΩ
500μf (CDBR500-50)
50 WVDC
TO GND TERM
82K
1.5K
43KΩ
470Ω
+ 39μf
1N753
4.7K
STANCOR TP-4
GREEN
WHITE/BLACK
e_o
OUTPUT
YELLOW
YELLOW/ BLACK
RED
2N697
2N697
2N697
2N697
2N3715
BLU/WHT
+ 39μf −
7.2V
50μf 20V
e_{in}
(WE 602A)
1.1VDC
0.5V
470Ω
NOTE 1
.001μf
4.7K
1.5K
1.5K
3.9K
11K
150Ω
51KΩ
470Ω
68Ω
68Ω
1Ω
1Ω
THERMISTOR 100Ω
+
−
2000μf 15WVDC (electrolytic)
e_o
BLK/WHT

NOTES:

1. 001 SUPPRESSES HIGH FREQUENCY OSCILLATION
2. SET R AT ROOM TEMP (75°F) FOR STANDBY CURRENT OF +80 mA. STANDBY CURRENT WILL BE < 150 mA FOR $45°F < T < 130°F$.
3. FOR A DEAD ZONE OF 20μV PK-PK, A VOLTAGE GAIN OF 10^5 IS REQUIRED TO DRIVE THIS AMPLIFIER WITH NO NEGATIVE FEEDBACK.
4. e_o AT MOTOR CONTROL WINDING MEASURED AT STALL, END OF TRAVEL.
5. THERMISTOR: FENWAL WA21W1, 100Ω AT 25°C.
6. e_{in} COMES FROM PIN V AMPLIFIER BOARD 3.

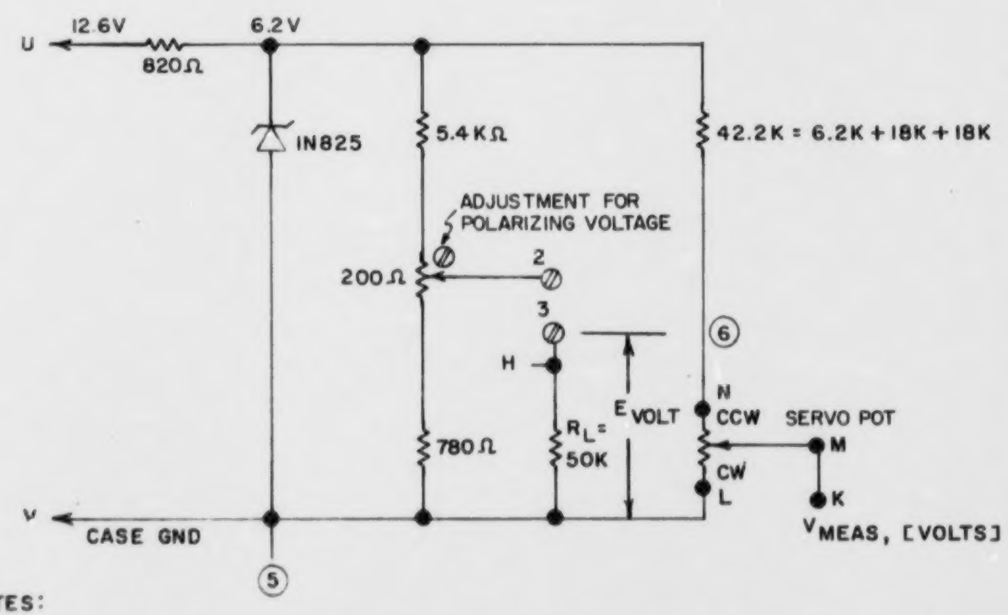
COMPLETED:	PFEIFFER	SERVO POWER AMPLIFIER
DATE:	12/28/65	
DRAWN:	MOAK	FIGURE 24
DATE:	9/17/66	

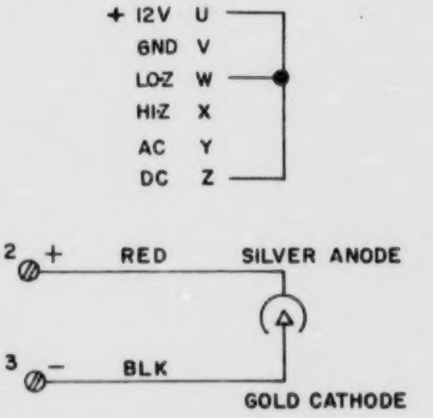

F36A FILAMENT TRANSFORMER
MR 1122
115 V AC
+
12 V FULL WAVE
RECTIFIED
–
TO FINAL STAGE
SERVO POWER AMPLIFIER

NOTE:

12 V FULL WAVE VOLTAGE CONNECTS TO CENTER TAP OF OUTPUT TRANSFORMER OF SERVO POWER AMPLIFIER, ALSO 12V FULL WAVE CONNECTS TO THE COLLECTOR OF THE 2N697'S.

COMPLETED:	BERTHELOT	POWER SUPPLY FOR FINAL STAGE SERVO POWER AMPLIFIER
DATE:	7/17/68	
DRAWN:	MOAK	FIGURE 25
DATE:	12/17/68	


U
12.6V
820Ω
6.2V
IN825
5.4KΩ
42.2K = 6.2K + 18K + 18K
ADJUSTMENT FOR POLARIZING VOLTAGE
200Ω
2
3
H
⑥
N
CCW
SERVO POT
M
K
CW
L
E VOLT
R L = 50K
780Ω
V
CASE GND
⑤
V MEAS, [VOLTS]


+ 12V U
GND V
LO-Z W
HI-Z X
AC Y
DC Z
2 +
RED
SILVER ANODE
3 −
BLK
GOLD CATHODE

ELECTRODE CURRENT:

$I_{AMP} = V_{MEAS}/5 \times 10^4$ OHMS

$= 2 \times 10^{-5} V_{MEAS} \left[\frac{VOLT}{OHM}\right]$

$I\mu A = 20 V_{MEAS}$

$V_{MEAS} = (1-N)(0.152)$, [VOLT] WHERE N= RECORDER SCALE READING RANGING FROM .0000 TO .9999

$I\mu A = 20(1-N)(0.152)$

$= 3.04(1-N)$

NOTES:

1. SLIDE WIRE (SERVO POT) CALIBRATION (N) IS 0.152 VOLT POSITIVE WITH RESPECT TO (L), MEASURED WITH DIGITEC DIGITAL VOLTMETER, 2.000 RANGE.
2. WHEN ELECTRODE NOT IN PLACE, PUT 1 MEG BETWEEN 2 AND 3.
3. ESTIMATED MAXIMUM ELECTRODE CURRENT = 2.5μA.
4. LETTERS REFER TO P.C. BOARD TERMINALS.
5. CCW: RECORDER DOWNSCALE. CW: RECORDER UPSCALE.
6. BECKMAN (MODIFIED) DISSOLVED OXYGEN ELECTRODE.

EXAMPLE OF CHARACTERISTIC FOR V ELECTRODE = .85V

$\left.\begin{array}{l}1.02\,\mu A \text{ AT } 35^\circ C\\ 0.57\,\mu A \text{ AT } 10^\circ C\end{array}\right\}$ IN AIR SATURATED WATER

COMPLETED:	WARREN
DATE:	5/1/66
DRAWN:	MOAK
DATE:	10/24/66

DISSOLVED OXYGEN

FIGURE 26

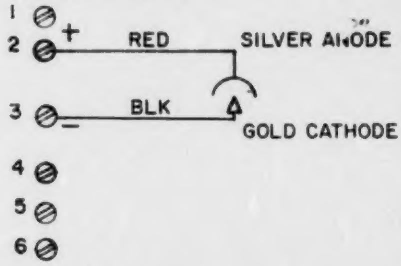
ELECTRODE CURRENT:

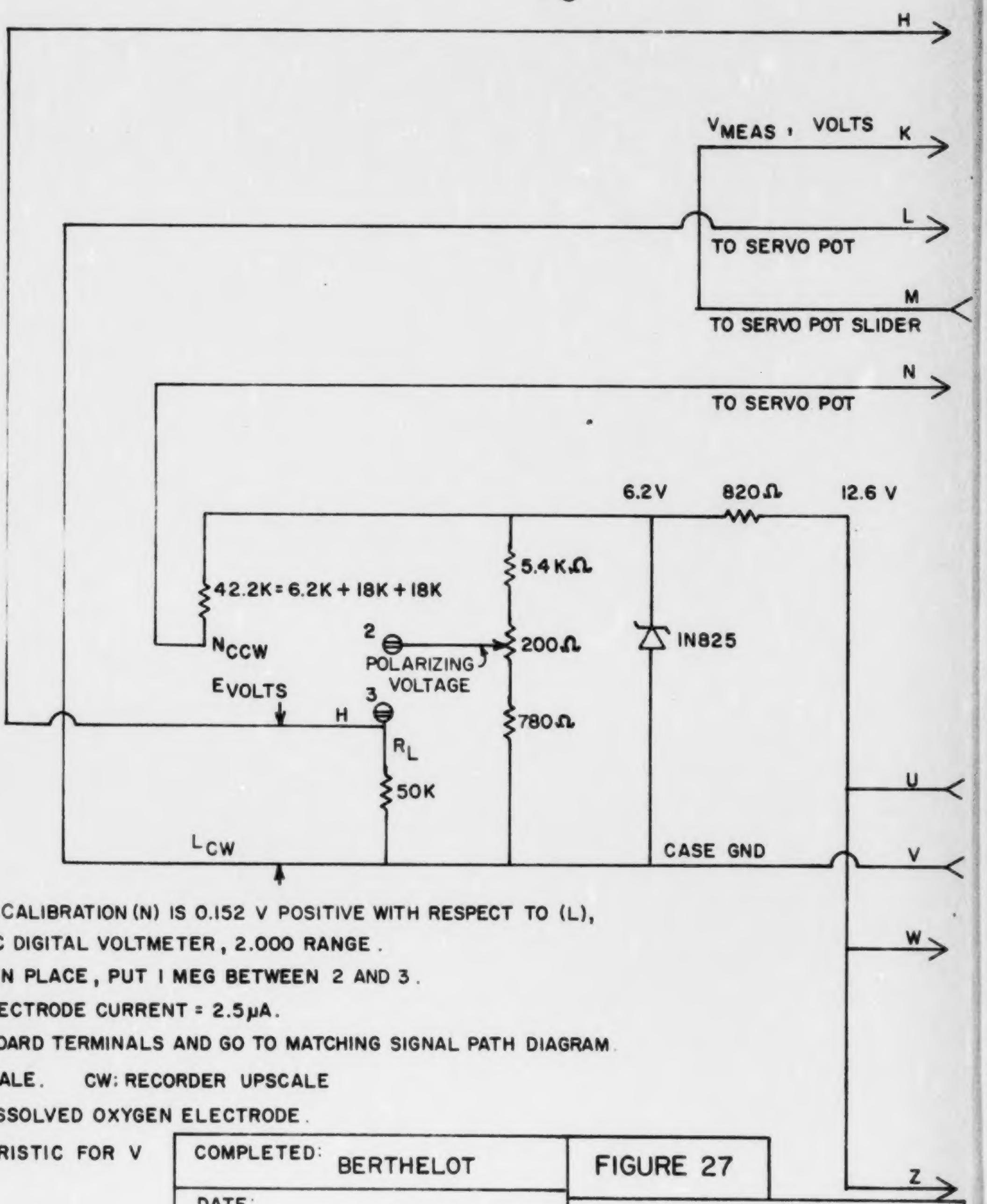
$$I_{AMP} = V_{MEAS} / 5 \times 10^4 \text{ OHMS}$$
$$= 2 \times 10^{-5} V_{MEAS} \left[\frac{\text{VOLT}}{\text{OHM}}\right]$$
$$I\mu A = 20 V_{MEAS}$$

$V_{MEAS} = (1-N)(0.152)$, [VOLT] WHERE N = RECORDER SCALE READING RANGING FROM .0000 TO .9999.

$$I\mu A = 20(1-N)(0.152)$$
$$= 3.04(1-N)$$

INPUT TERMINAL BOARD


1
2 +
RED
SILVER ANODE
3 −
BLK
GOLD CATHODE
4
5
6


H
VMEAS , VOLTS
K
L
TO SERVO POT
M
TO SERVO POT SLIDER
N
TO SERVO POT
6.2V
820Ω
12.6 V
5.4 KΩ
42.2K = 6.2K + 18K + 18K
NCCW
2
POLARIZING VOLTAGE
200Ω
IN825
EVOLTS
3
H
780Ω
RL
50K
U
LCW
CASE GND
V
W
Z

NOTES:

1. SLIDE WIRE (SERVO POT) CALIBRATION (N) IS 0.152 V POSITIVE WITH RESPECT TO (L), MEASURED WITH DIGITEC DIGITAL VOLTMETER, 2.000 RANGE.
2. WHEN ELECTRODE NOT IN PLACE, PUT 1 MEG BETWEEN 2 AND 3.
3. ESTIMATED MAXIMUM ELECTRODE CURRENT = 2.5μA.
4. LETTERS REFER TO PC BOARD TERMINALS AND GO TO MATCHING SIGNAL PATH DIAGRAM.
5. CCW: RECORDER DOWNSCALE. CW: RECORDER UPSCALE
6. BECKMAN (MODIFIED) DISSOLVED OXYGEN ELECTRODE.

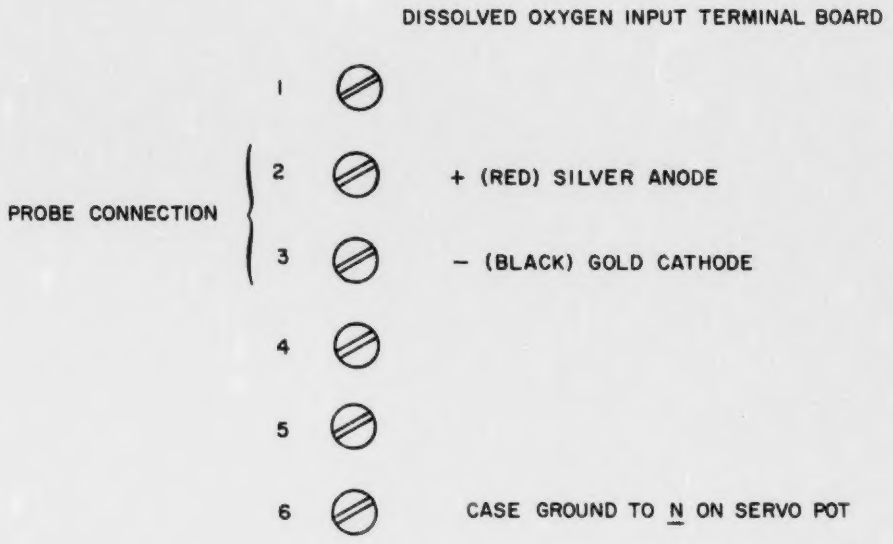
   EXAMPLE OF CHARACTERISTIC FOR V

   ELECTRODE = 0.85 V

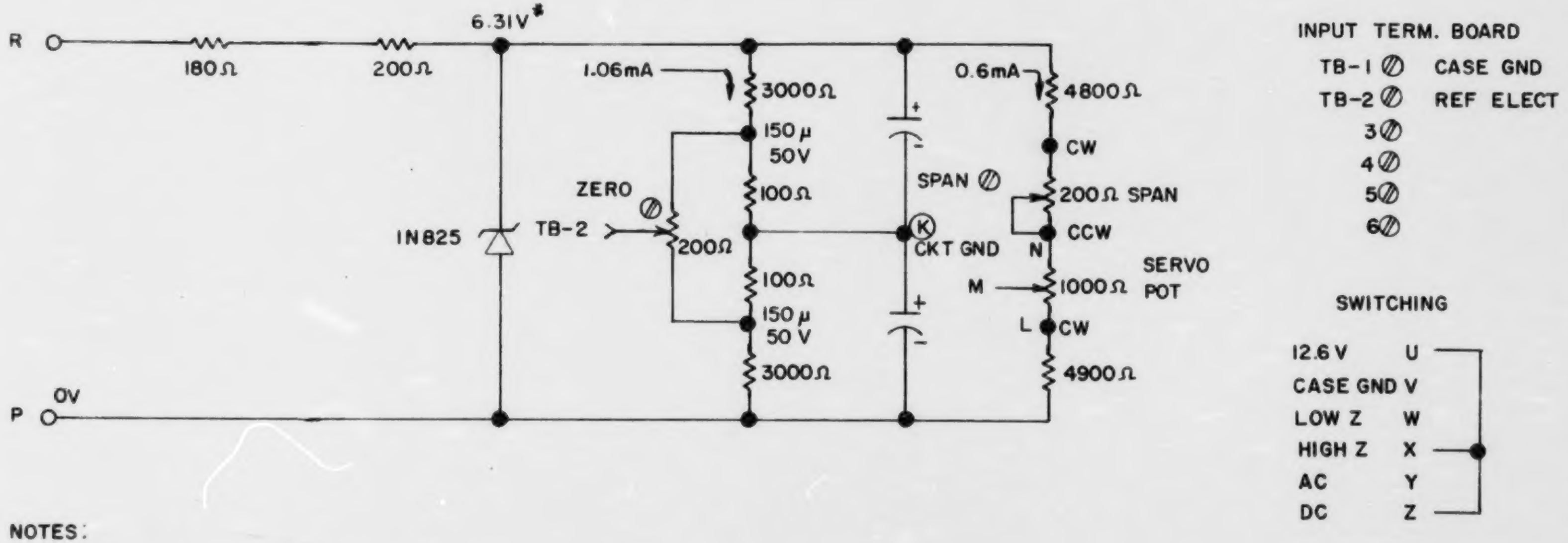
   1.02μA AT 35°C } IN AIR SATURATED WATER

   0.57μA AT 10°C }
7. 6 CONNECTS TO N FOR CHECKING PURPOSES.

COMPLETED: BERTHELOT	FIGURE 27
DATE: 12/12/67	DISSOLVED OXYGEN PARAMETER PC BOARD
DRAWN: MOAK	
DATE: 12/12/67	


DISSOLVED OXYGEN INPUT TERMINAL BOARD
1
PROBE CONNECTION
2
+ (RED) SILVER ANODE
3
− (BLACK) GOLD CATHODE
4
5
6
CASE GROUND TO N ON SERVO POT

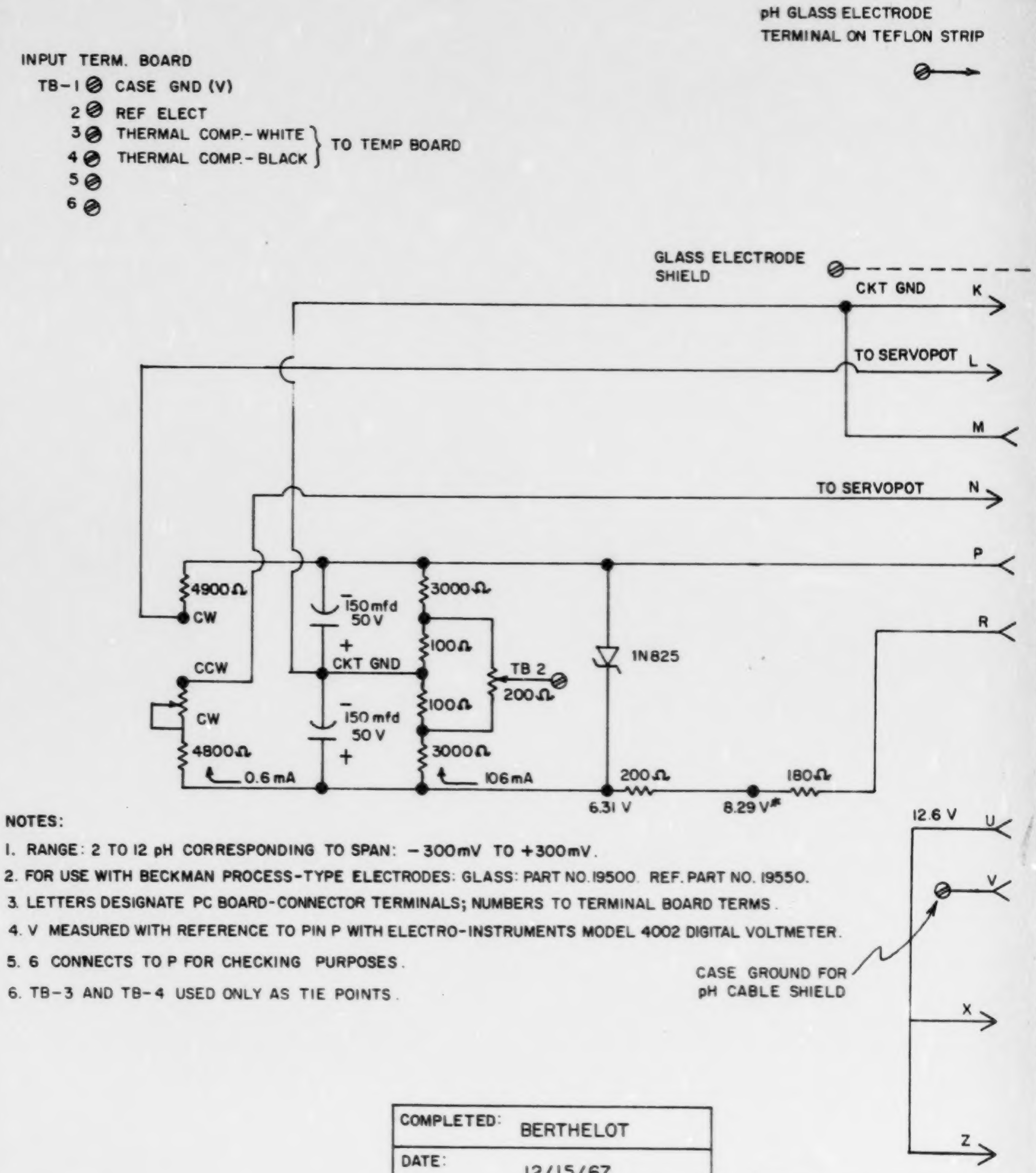
COMPLETED:	WARREN	DISSOLVED OXYGEN PROBE CONNECTION TO INPUT TERMINAL BOARD
DATE:	4/23/65	
DRAWN:	MOAK	FIGURE 28
DATE:	4/15/68	


R
180Ω
200Ω
6.31V*
P
0V
1N825
TB-2
ZERO ⊘
200Ω
1.06mA
3000Ω
150µ 50V
100Ω
100Ω
150µ 50 V
3000Ω
SPAN ⊘
K
CKT GND
0.6mA
4800Ω
CW
200Ω SPAN
CCW
N
M
1000Ω SERVO POT
L
CW
4900Ω
INPUT TERM. BOARD
TB-1 ⊘ CASE GND
TB-2 ⊘ REF ELECT
3⊘
4⊘
5⊘
6⊘
SWITCHING
12.6 V U
CASE GND V
LOW Z W
HIGH Z X
AC Y
DC Z

NOTES:

1. RANGE: 2 TO 12 pH CORRESPONDING TO SPAN: − 300 mV TO + 300 mV
2. FOR USE WITH BECKMAN PROCESS-TYPE ELECTRODES: GLASS: PART NO. 19500. REFERENCE PART NO. 19550.
3. LETTERS DESIGNATE P.C. BOARD-CONNECTOR TERMINALS; NUMBERS TO TERMINAL BOARD TERMS.
4. V* MEASURED WITH REFERENCE TO PIN P WITH ELECTRO-INSTRUMENTS MODEL 4002 DIGITAL VOLTMETER.

COMPLETED:	WARREN	pH
DATE:	3/22/66	
DRAWN:	MOAK	FIGURE 29
DATE:	10/26/66	


pH GLASS ELECTRODE
TERMINAL ON TEFLON STRIP
INPUT TERM. BOARD
TB-1 CASE GND (V)
2 REF ELECT
3 THERMAL COMP.- WHITE
4 THERMAL COMP.- BLACK
TO TEMP BOARD
5
6
GLASS ELECTRODE SHIELD
CKT GND
K
TO SERVOPOT
L
M
TO SERVOPOT
N
P
R
4900Ω
CW
150 mfd 50 V
3000Ω
100Ω
CKT GND
TB 2
200Ω
1N825
CCW
CW
150 mfd 50 V
100Ω
4800Ω
3000Ω
0.6 mA
106 mA
200Ω
180Ω
6.31 V
8.29 V*
12.6 V
U
V
CASE GROUND FOR pH CABLE SHIELD
X
Z

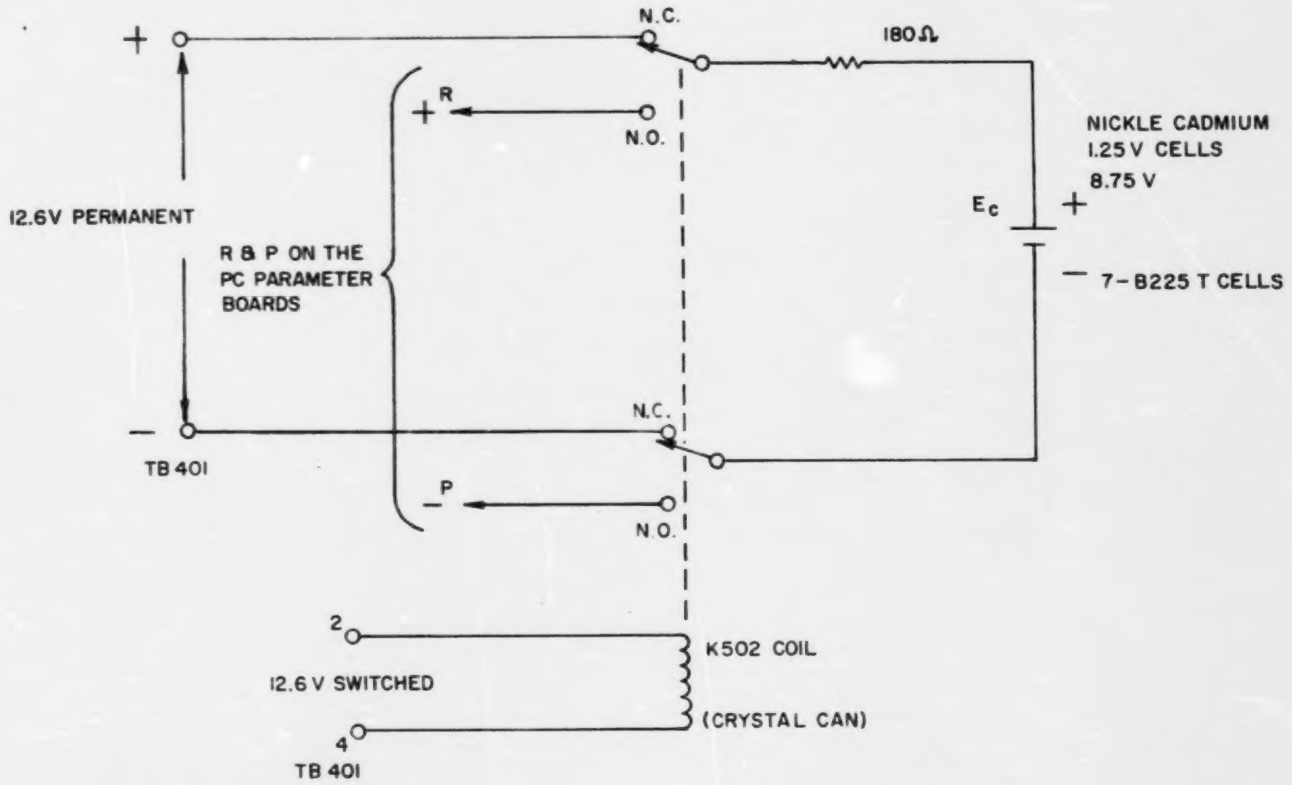
NOTES:

1. RANGE: 2 TO 12 pH CORRESPONDING TO SPAN: −300mV TO +300mV.
2. FOR USE WITH BECKMAN PROCESS-TYPE ELECTRODES: GLASS: PART NO. 19500. REF. PART NO. 19550.
3. LETTERS DESIGNATE PC BOARD-CONNECTOR TERMINALS; NUMBERS TO TERMINAL BOARD TERMS.
4. V MEASURED WITH REFERENCE TO PIN P WITH ELECTRO-INSTRUMENTS MODEL 4002 DIGITAL VOLTMETER.
5. 6 CONNECTS TO P FOR CHECKING PURPOSES.
6. TB-3 AND TB-4 USED ONLY AS TIE POINTS.

COMPLETED:	BERTHELOT
DATE:	12/15/67
DRAWN:	MOAK
DATE:	12/19/67

pH

FIGURE 30

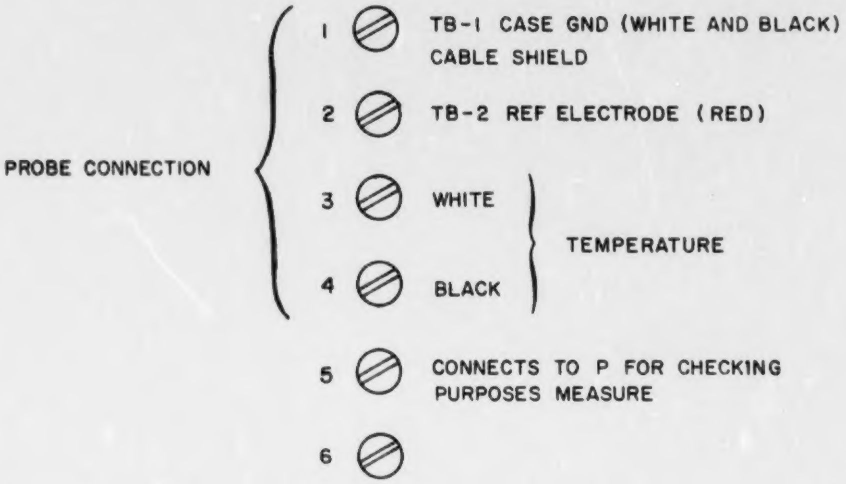

+
N.C.
180Ω
+ R
N.O.
NICKLE CADMIUM
1.25 V CELLS
8.75 V
12.6V PERMANENT
E_c
+
R & P ON THE
PC PARAMETER
BOARDS
— 7-B225 T CELLS
N.C.
—
TB 401
— P
N.O.
2
K502 COIL
12.6 V SWITCHED
(CRYSTAL CAN)
4
TB 401

NOTES:

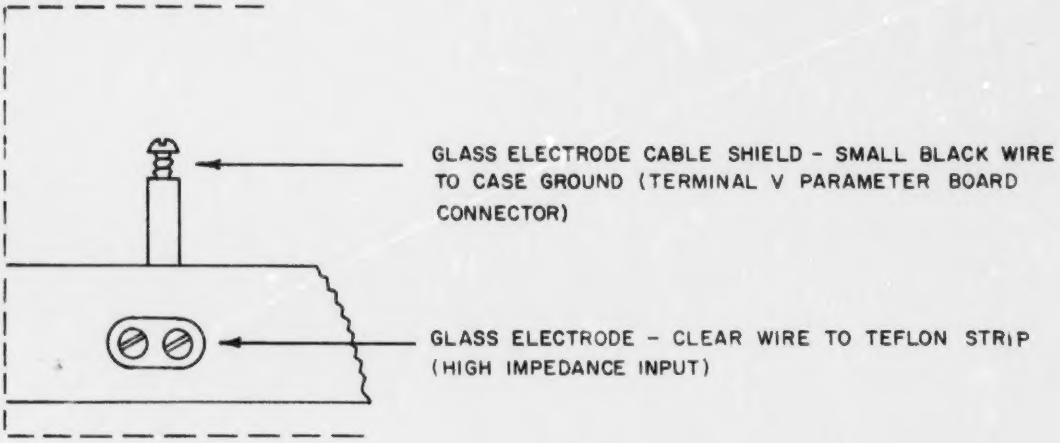
1. USED IN PLACE OF 12V DC FLOATING SUPPLY.
2. TB401 SHOWN IN PROGRAMMER (400) DIAGRAM 10/31/66.

COMPLETED:	BERTHELOT	BATTERY SUPPLY FOR pH
DATE:	11/5/68	
DRAWN:	MOAK	FIGURE 31
DATE:	12/18/68	

pH INPUT TERMINAL BOARD


PROBE CONNECTION
1 TB-1 CASE GND (WHITE AND BLACK) CABLE SHIELD
2 TB-2 REF ELECTRODE (RED)
3 WHITE
4 BLACK
TEMPERATURE
5 CONNECTS TO P FOR CHECKING PURPOSES MEASURE
6

pH GLASS ELECTRODE HIGH IMPEDANCE CONNECTION


GLASS ELECTRODE CABLE SHIELD - SMALL BLACK WIRE TO CASE GROUND (TERMINAL V PARAMETER BOARD CONNECTOR)
GLASS ELECTRODE - CLEAR WIRE TO TEFLON STRIP (HIGH IMPEDANCE INPUT)

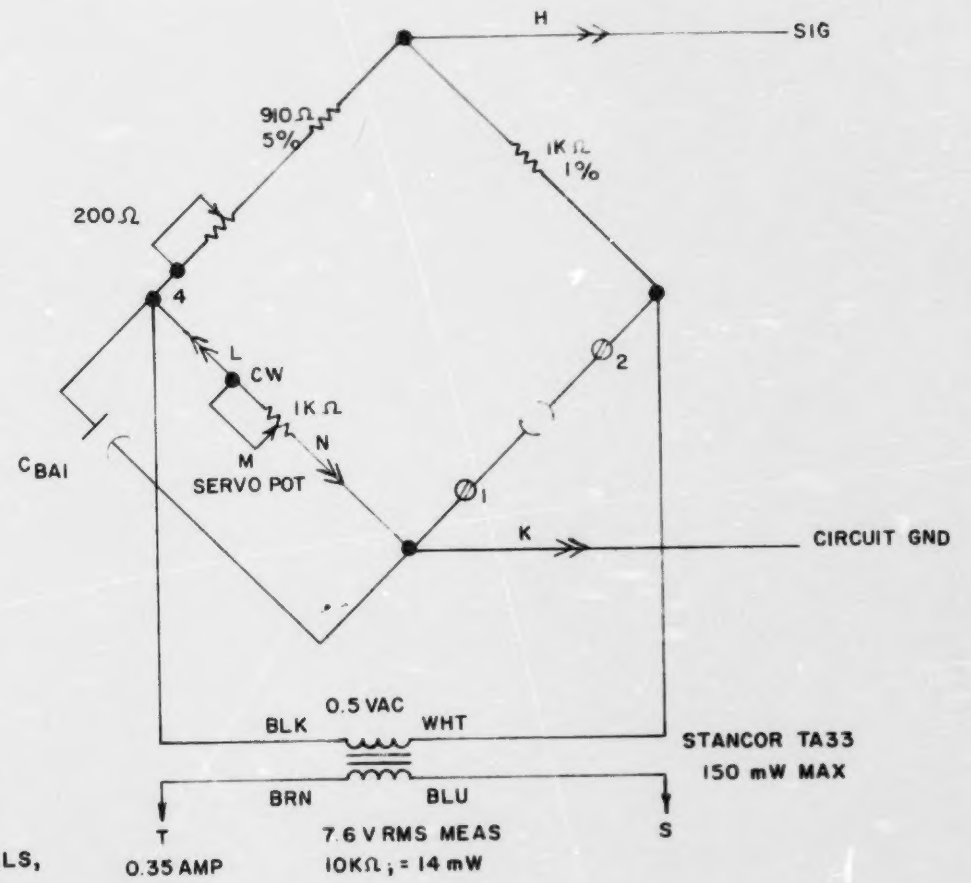
COMPLETED:	WARREN	pH PROBE CONNECTIONS
DATE:	4/12/65	
DRAWN:	MOAK	FIGURE 32
DATE:	11/12/68	

INPUT TERMINAL BOARD

1 ⊘ CONDUC. CELL
2 ⊘ CONDUC. CELL
3 ⊘
4 ⊘
5 ⊘
6 ⊘

SWITCHING

12.6 U
GND V —
LO-Z W ●
HI-Z X —
AC Y


H
SIG
910Ω
5%
1KΩ
1%
200Ω
4
L
CW
1KΩ
N
M
SERVO POT
C_{BAl}
2
1
K
CIRCUIT GND
0.5 VAC
BLK
WHT
BRN
BLU
T
S
STANCOR TA33
150 mW MAX
0.35 AMP
7.6 V RMS MEAS
10KΩ; = 14 mW

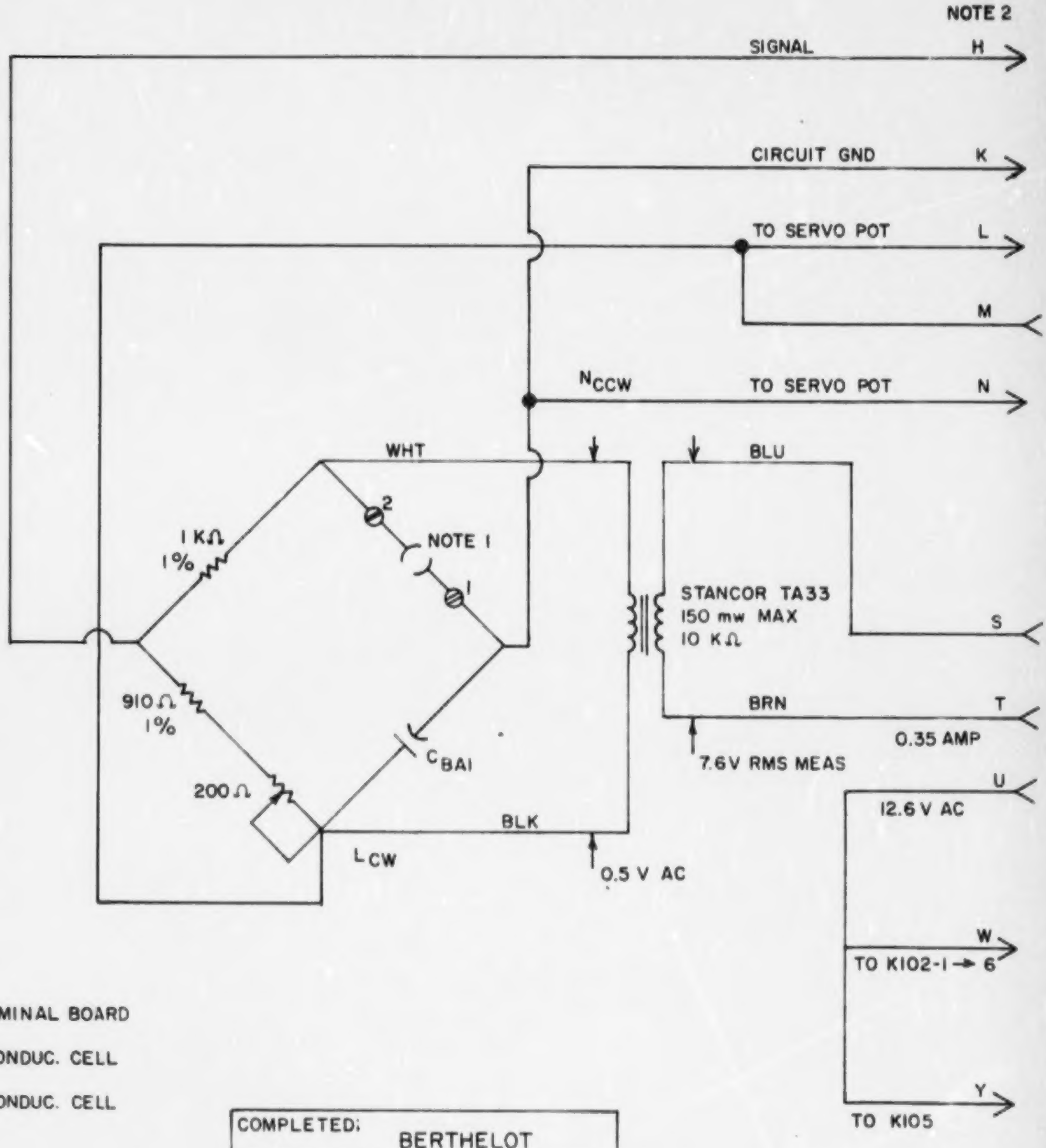
NOTES:

1. FOR CELL CONSTANT K = 0.1 (L = K/R):
   95.00 RECORDER SCALE = 950 Ω = 105 μMHOS
   5.00 RECORDER SCALE = 50 Ω = 2000 μMHOS
2. LETTERS DESIGNATE P.C. CONNECTOR TERMINALS, NUMBERS DESIGNATE TERMINAL BOARD TERMINALS.
3. C_{BAL} = 0.037μf FOR CELL CEZ-V501 INSTALLED MAY 11, 1966
4. SERVO POT = 1010Ω

COMPLETED:	WARREN	CONDUCTIVITY
DATE:	12/6/65	
DRAWN:	MOAK	FIGURE 33
DATE:	10/21/66	

NOTES:

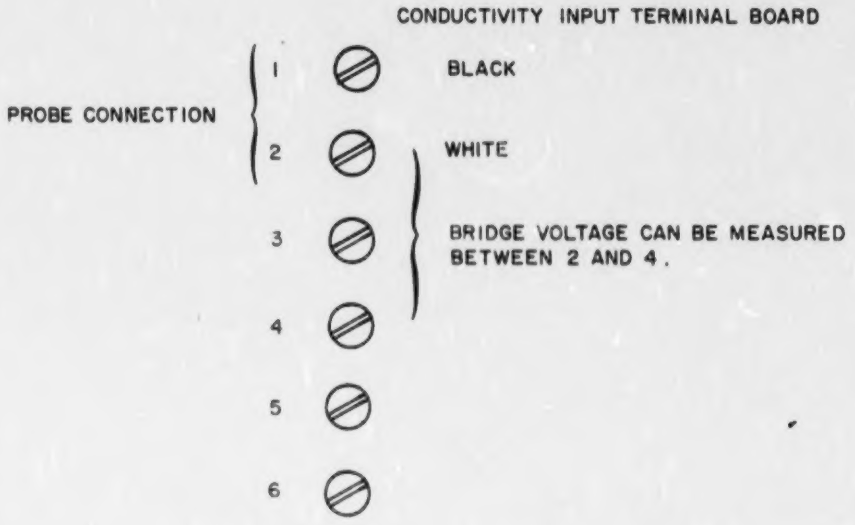
1. FOR CELL CONSTANT K = 0.1, (L = K/R): 9500 RECORDER SCALE = 950Ω ∴ L = 105 μMHOS
   500 RECORDER SCALE = 50Ω ∴ L = 2000 μMHOS
2. LETTERS DESIGNATE P.C. CONNECTOR TERMINALS, NUMBERS DESIGNATE TERMINAL BOARD TERMINALS.
3. C_{BAI} = 0.037 μf FOR CELL CEZ-V501 INSTALLED MAY 11, 1966. (NOT USED - 12/26/67).
4. SERVO POT = 1010Ω


NOTE 2
SIGNAL
H
CIRCUIT GND
K
TO SERVO POT
L
M
N_{CCW}
TO SERVO POT
N
WHT
BLU
2
1 KΩ
1%
NOTE 1
1
STANCOR TA33
150 mw MAX
10 KΩ
S
BRN
T
0.35 AMP
910Ω
1%
C_{BAI}
7.6V RMS MEAS
200Ω
U
12.6 V AC
BLK
L_{CW}
0.5 V AC
W
TO K102-1 → 6
Y
TO K105

INPUT TERMINAL BOARD

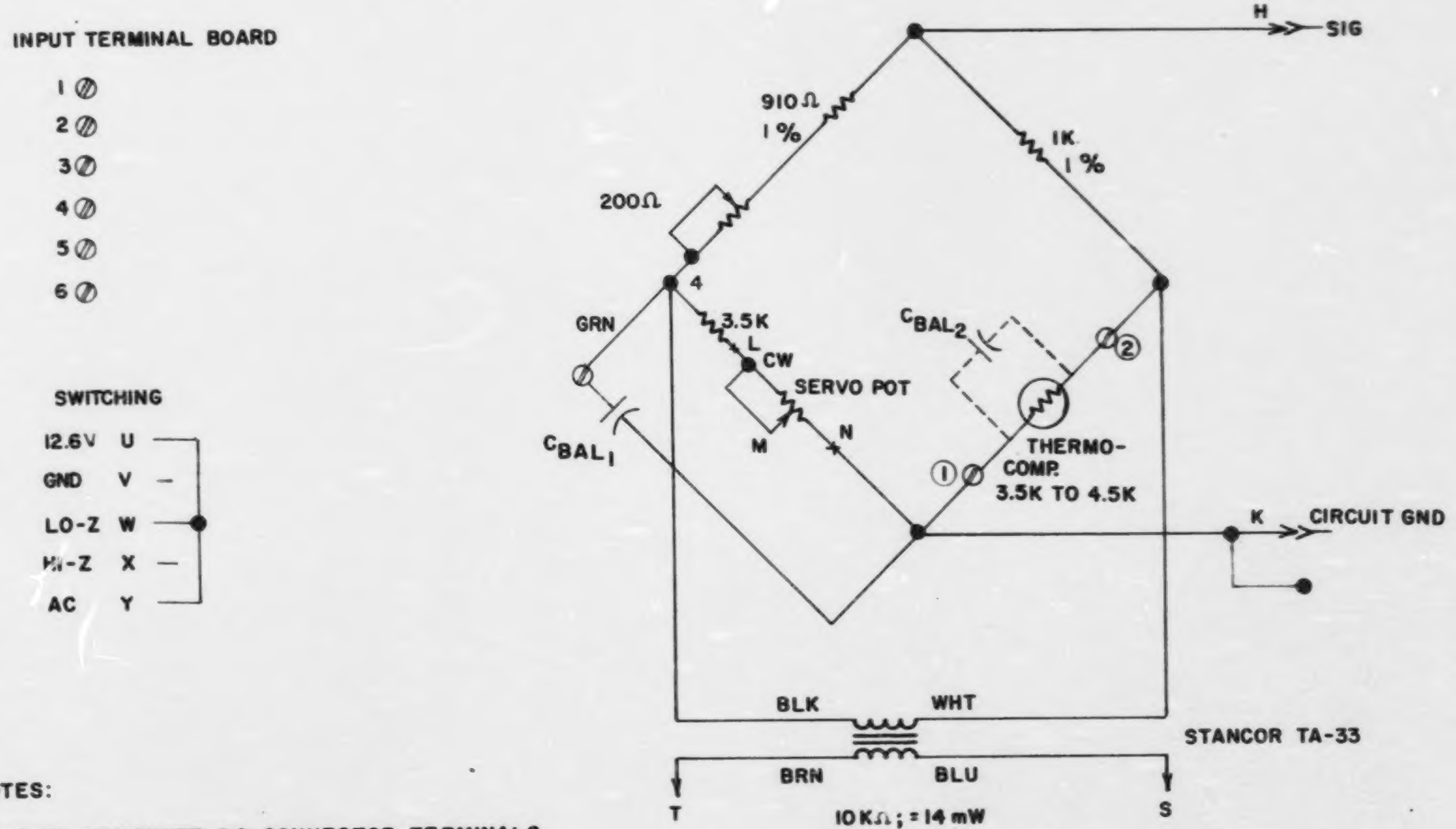
1 ⊘ CONDUC. CELL
2 ⊘ CONDUC. CELL
3 ⊘
4 ⊘
5 ⊘
6 ⊘

COMPLETED:	BERTHELOT	
DATE:	12/12/67	CONDUCTIVITY PARAMETER PC BOARD LOW Z
DRAWN:	MOAK	
DATE:	12/12/67	FIGURE 34


CONDUCTIVITY INPUT TERMINAL BOARD
PROBE CONNECTION
1
BLACK
2
WHITE
3
BRIDGE VOLTAGE CAN BE MEASURED BETWEEN 2 AND 4.
4
5
6

NOTE: SHIELD ON CONDUCTIVITY LEAD GOES TO CASE GROUND.

COMPLETED:	WARREN	CONDUCTIVITY PROBE CONNECTION TO INPUT TERMINAL BOARD
DATE:	3/17/65	
DRAWN:	MOAK	
DATE:	4/15/68	FIGURE 35


INPUT TERMINAL BOARD
1
2
3
4
5
6
SWITCHING
12.6V U
GND V
LO-Z W
HI-Z X
AC Y
H
SIG
910Ω
1%
1K
1%
200Ω
4
GRN
3.5K
L
CW
SERVO POT
M
N
C_{BAL_1}
C_{BAL_2}
②
①
THERMO-
COMP.
3.5K TO 4.5K
K
CIRCUIT GND
BLK
WHT
BRN
BLU
STANCOR TA-33
T
S
10 KΩ ; = 14 mW

NOTES:

1. LETTERS DESIGNATE P.C. CONNECTOR TERMINALS, NUMBERS DESIGNATE TERMINAL BOARD TERMINALS.
2. C_{BAL_2} = 0.015 μf FOR BECKMAN 19017 THERMOCOMPENSATOR.

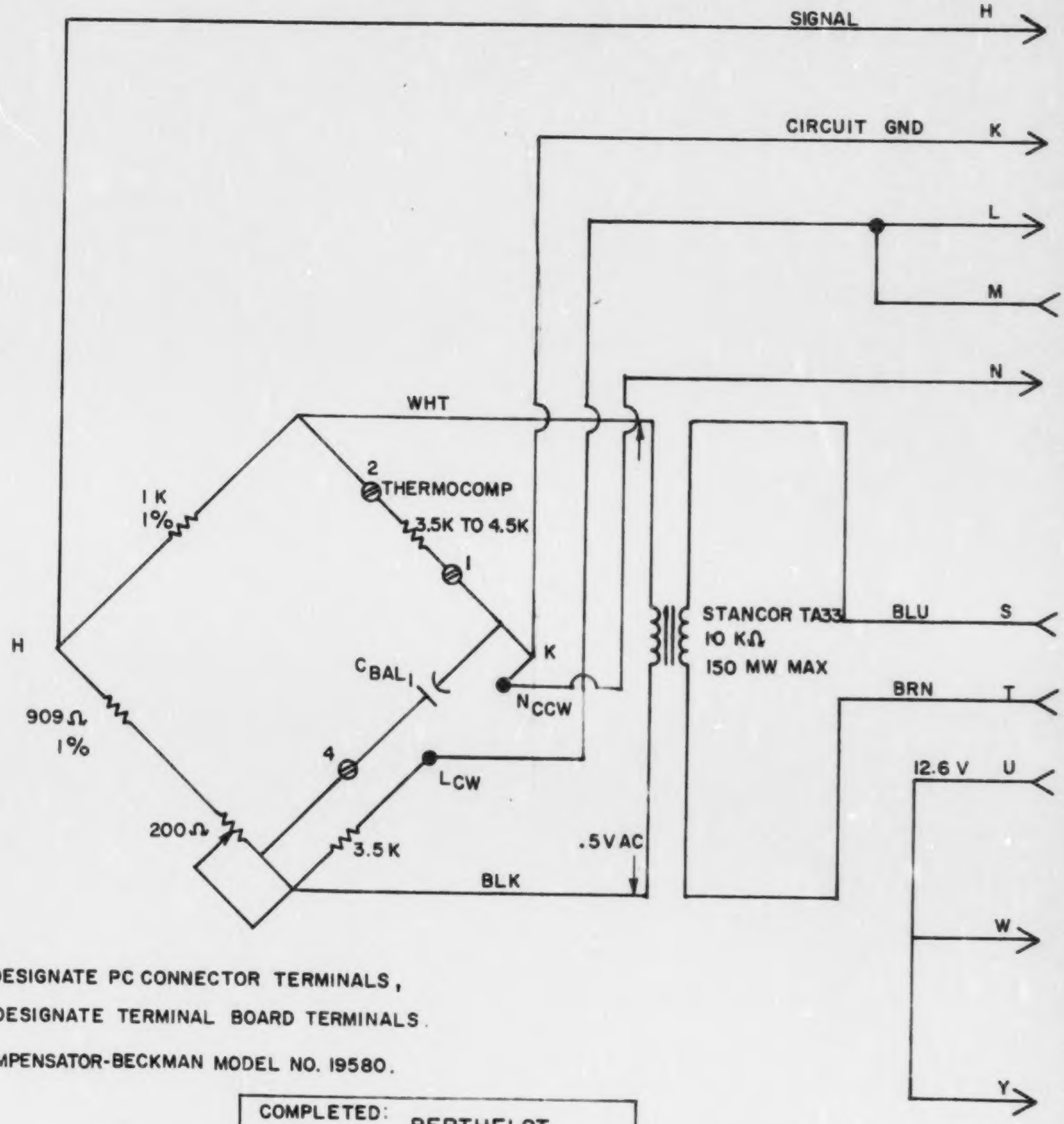
COMPLETED:	WARREN
DATE:	4/12/66
DRAWN:	MOAK
DATE:	10/26/66

TEMPERATURE

FIGURE 36

INPUT TERMINAL BOARD

1 ⊘ }
2 ⊘ } TEMP. SENSOR (FOR WATER TEMP., LEADS FROM 3 AND 4 ON pH TERMINAL BOARD.)
3 ⊘
4 ⊘ - TEST POINT. TERMINALS 2 AND 4 TRANSFORMER SEC.
5 ⊘
6 ⊘


SIGNAL
H
CIRCUIT GND
K
L
M
N
WHT
2
THERMOCOMP
1 K
1%
3.5K TO 4.5K
1
H
K
C_{BAL_1}
N_{CCW}
909Ω
1%
4
L_{CW}
200Ω
3.5 K
.5 V AC
BLK
STANCOR TA33
10 KΩ
150 MW MAX
BLU
S
BRN
T
12.6 V
U
W
Y

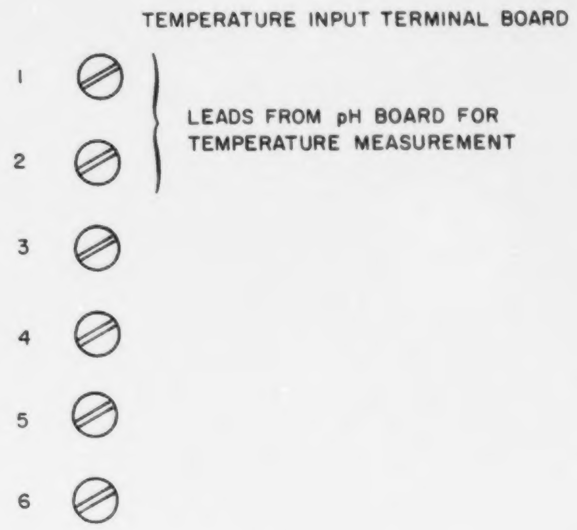
NOTES:

1. LETTERS DESIGNATE PC CONNECTOR TERMINALS, NUMBERS DESIGNATE TERMINAL BOARD TERMINALS.
2. THERMOCOMPENSATOR-BECKMAN MODEL NO. 19580.

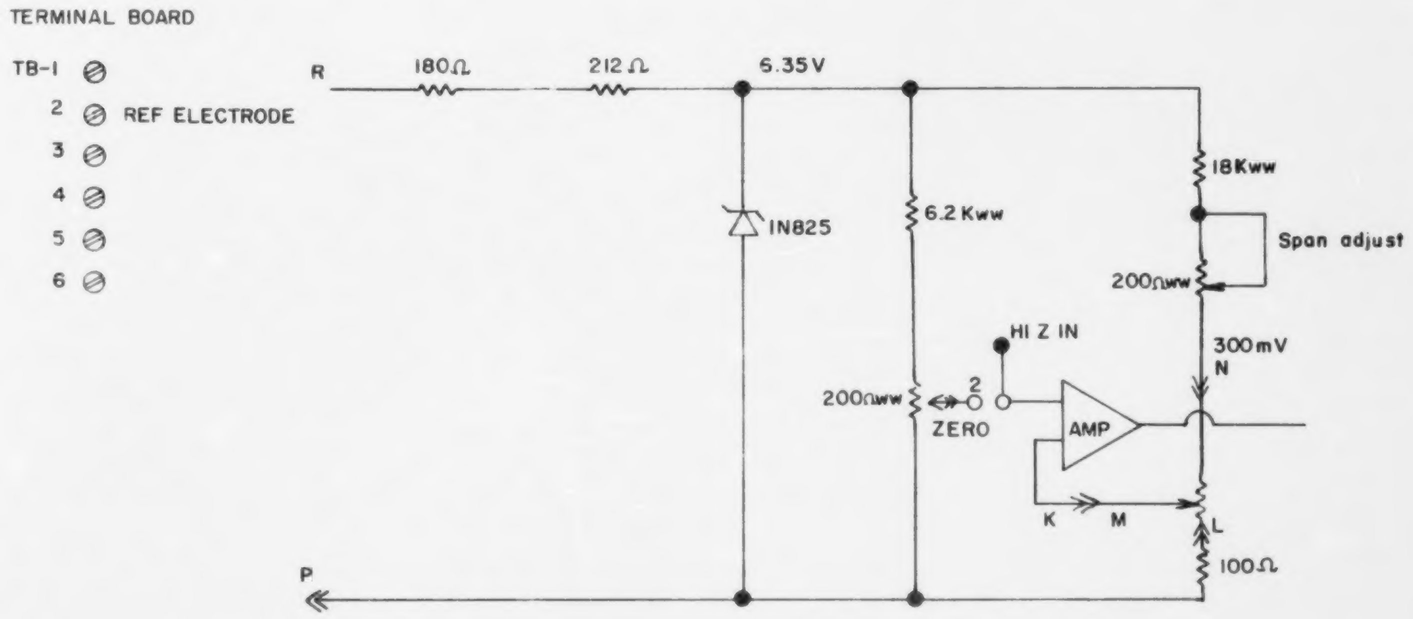
COMPLETED:	BERTHELOT
DATE:	12/12/67
DRAWN:	MOAK
DATE:	12/13/67

TEMPERATURE

FIGURE 37


TEMPERATURE INPUT TERMINAL BOARD
1
2
3
4
5
6
LEADS FROM pH BOARD FOR TEMPERATURE MEASUREMENT

COMPLETED :	WARREN	TEMPERATURE PROBE CONNECTION TO INPUT TERMINAL BOARD
DATE :	4/10/65	
DRAWN :	MOAK	FIGURE 38
DATE :	4/15/68	


TERMINAL BOARD
TB-1
2
REF ELECTRODE
3
4
5
6
R
180Ω
212Ω
6.35V
IN825
6.2 Kww
200Ωww
ZERO
2
HI Z IN
AMP
18Kww
Span adjust
200Ωww
300mV
N
K
M
L
100Ω
P

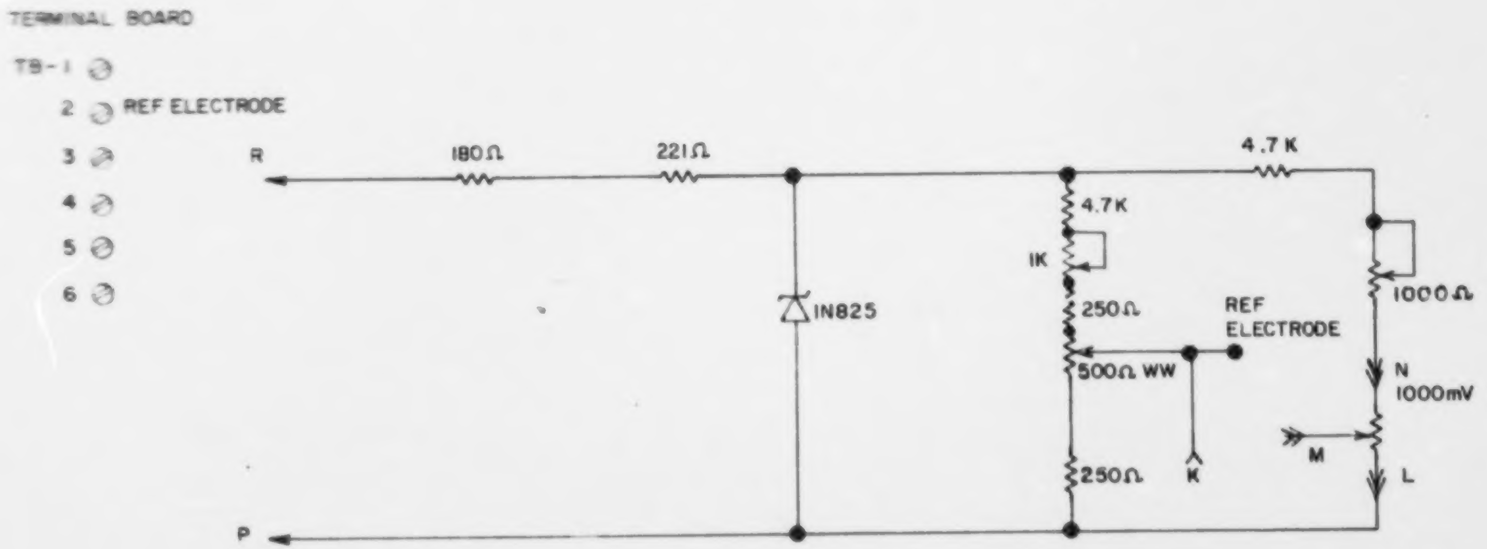
0-10 PPM CHLORIDE . ~300mV
1000 " " 120 mV
10,000 " " ~0 mV

0mV = 10,000 DIV
300mV = 0 DIV

NOTES:

1. CHLORIDE ELECTRODE CONNECTS TO HI Z INPUT

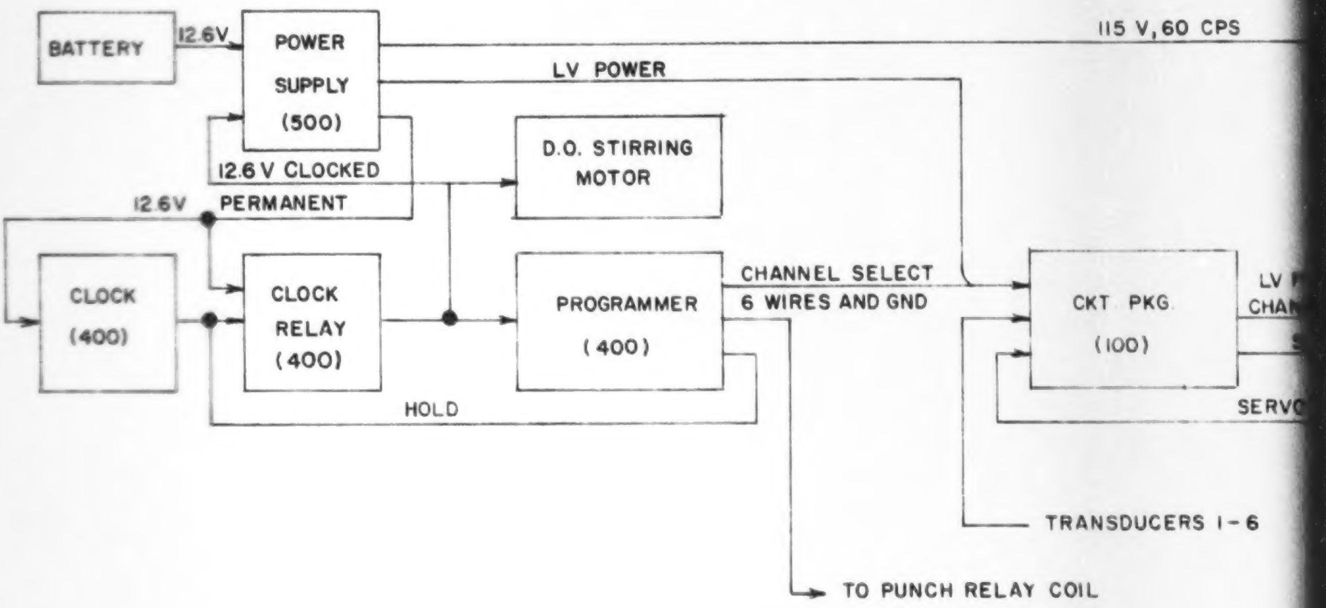
COMPLETED:	MILLER	CHLORIDE BOARD
DATE:	4/5/65	
DRAWN:	MOAK	FIGURE 39
DATE:	10/17/66	

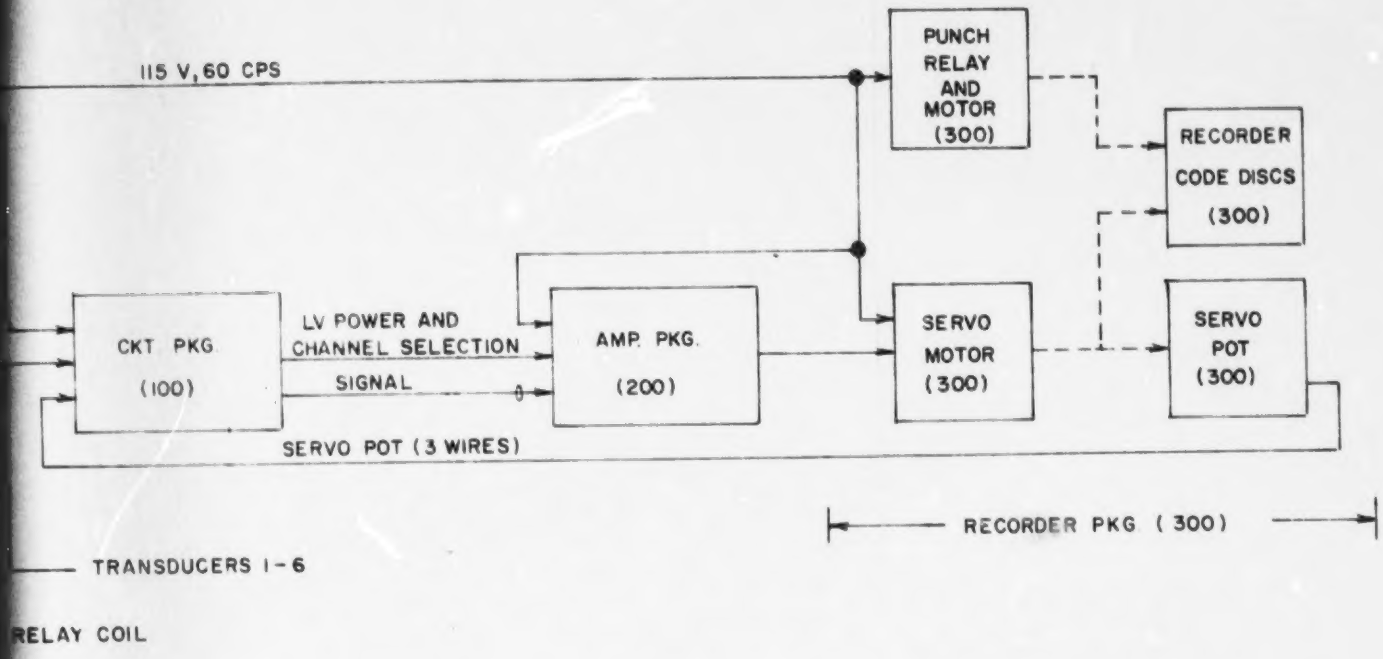

TERMINAL BOARD
TB-1
2 REF ELECTRODE
3
4
5
6
R
P
180Ω
221Ω
IN825
4.7K
IK
250Ω
500Ω WW
250Ω
REF ELECTRODE
K
4.7 K
1000Ω
N
1000mV
M
L

NOTES:

1. PLATINUM REDOX ELECTRODE CONNECTS TO HI Z INPUT.

COMPLETED:	RAIBLE	REDOX BOARD
DATE:	4/13/65	
DRAWN:	MOAK	FIGURE 40
DATE:	10/27/66	


BATTERY
12.6V
POWER SUPPLY (500)
115 V, 60 CPS
LV POWER
12.6 V CLOCKED
D.O. STIRRING MOTOR
12.6V
PERMANENT
CLOCK (400)
CLOCK RELAY (400)
PROGRAMMER (400)
CHANNEL SELECT
6 WIRES AND GND
CKT PKG. (100)
LV
CHAN
SERVO
HOLD
TRANSDUCERS 1-6
TO PUNCH RELAY COIL


115 V, 60 CPS
PUNCH RELAY AND MOTOR (300)
RECORDER CODE DISCS (300)
CKT. PKG. (100)
LV POWER AND CHANNEL SELECTION
SIGNAL
AMP. PKG. (200)
SERVO MOTOR (300)
SERVO POT (300)
SERVO POT (3 WIRES)
RECORDER PKG (300)
TRANSDUCERS 1-6
RELAY COIL

COMPLETED	WARREN
DATE:	6/1/66
DRAWN:	MOAK
DATE:	11/7/66

SUB CHASSIS NUMBERING ASSIGNMENTS

FIGURE 41

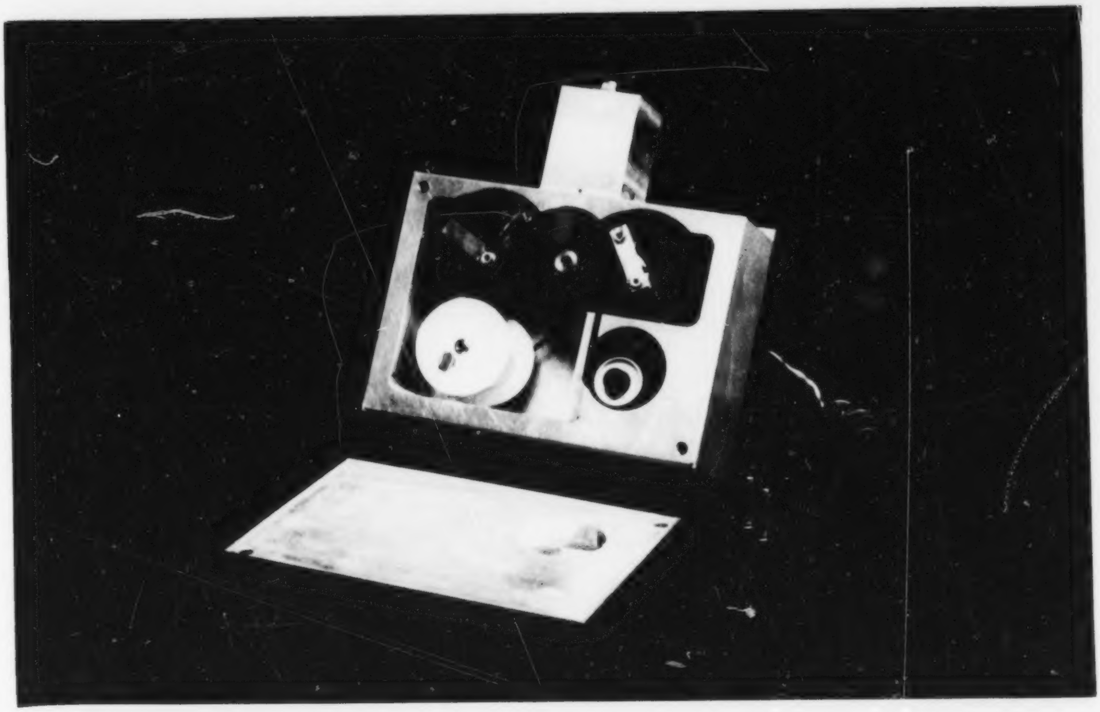


Figure 42. Photographic Recorder

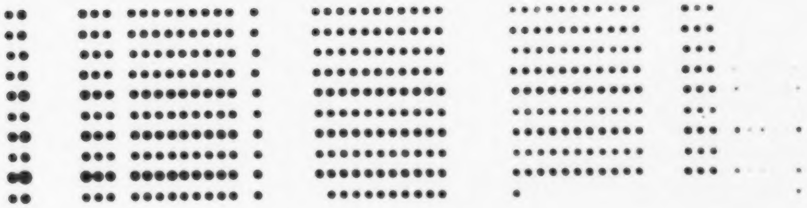


Figure 43. Enlargement of Film from Photographic Recorder

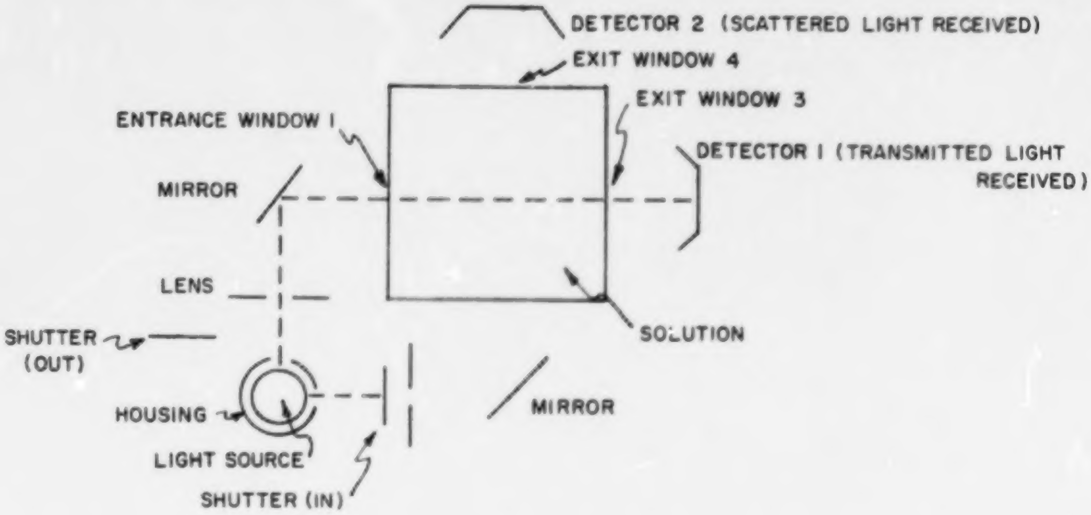
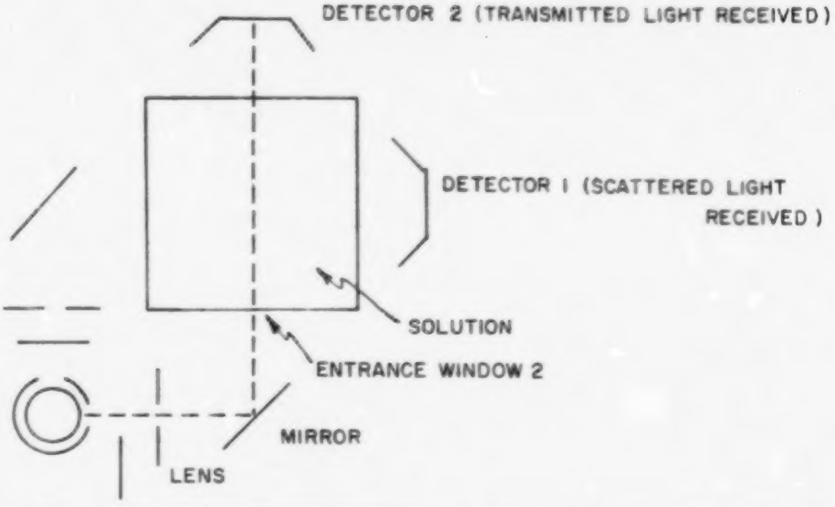
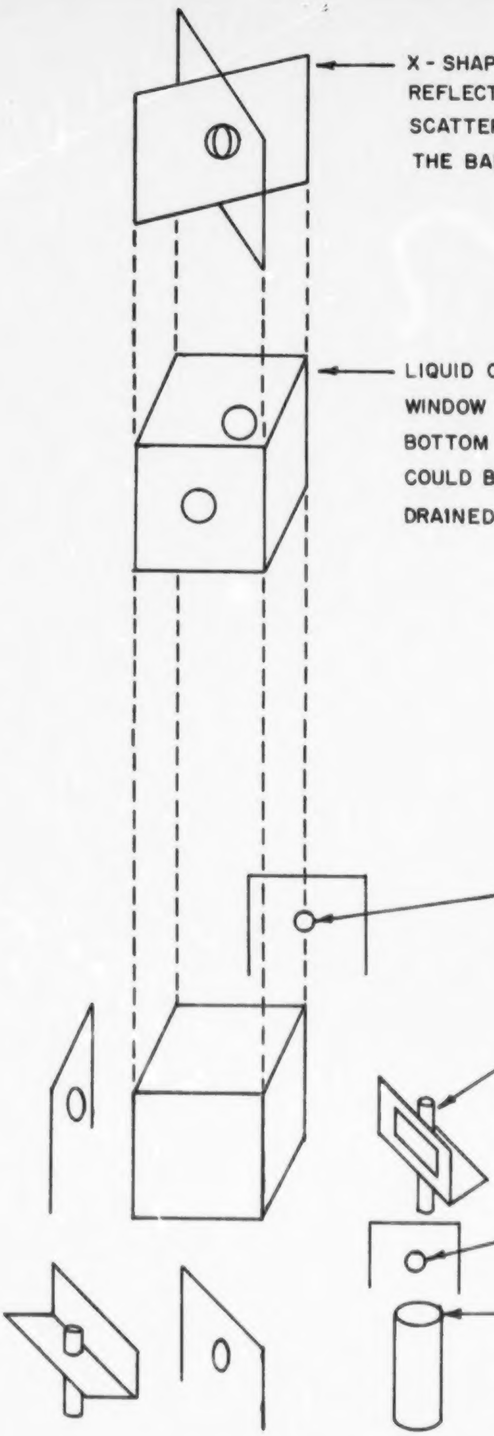

DETECTOR 2 (SCATTERED LIGHT RECEIVED)
EXIT WINDOW 4
EXIT WINDOW 3
ENTRANCE WINDOW 1
DETECTOR 1 (TRANSMITTED LIGHT RECEIVED)
MIRROR
LENS
SHUTTER (OUT)
SOLUTION
HOUSING
MIRROR
LIGHT SOURCE
SHUTTER (IN)

FIGURE 44
CONDITION 1

FIGURE 45
CONDITION 2


DETECTOR 2 (TRANSMITTED LIGHT RECEIVED)
DETECTOR 1 (SCATTERED LIGHT RECEIVED)
SOLUTION
ENTRANCE WINDOW 2
MIRROR
LENS

COMPLETED:	FERGUSON	CONDITIONS FOR RATIO OF SCATTERED LIGHT TO TRANSMITTED LIGHT
DATE:	5/20/64	
DRAWN:	MOAK	FIGURES 44 & 45
DATE:	11/23/68	



X - SHAPED BAFFLE PLACED IN CELL TO CUT DOWN MULTIPLE REFLECTIONS WITHIN THE CELL. THIS CONFINED THE SCATTERING VOLUME TO THE SIZE OF THE OPENINGS IN THE BAFFLE. PAINTED BLACK.

LIQUID CELL - PAINTED BLACK EXCEPT FOR WINDOWS. WINDOW ON EACH OF FOUR SIDES. TOP OF CELL OPEN. BOTTOM HAS DRAIN THROUGH STOPCOCK, SO THAT CELL COULD BE LEFT IN PLACE IN THE OPTIC PATH AND DRAINED THROUGH THE STOPCOCK.

CDS DETECTOR RCA 7163

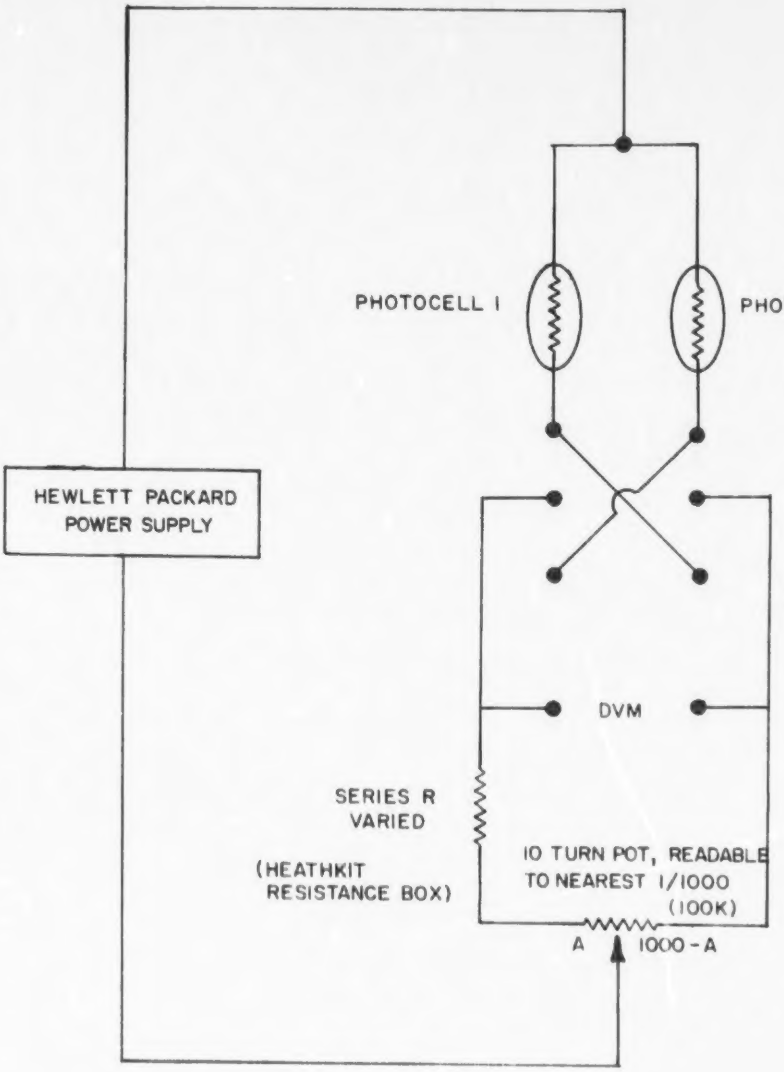
REFLECTING MIRROR - ALUMINUM ANGLE WITH SCREW SUPPORT TO ADJUST HEIGHT AND ANGLE. FRONT SURFACE MIRROR EPOXIED TO THE ANGLE.

COLLIMATING LENS

LIGHT SOURCE - BECKMAN DU 6V LAMP WITHIN METAL HOUSING. HOUSING HAS CIRCULAR OPENINGS ON THE TWO OPTICAL AXES.

COMPLETED:	FERGUSON	LIQUID CELL AND BAFFLE
DATE:	5/16/64	
DRAWN:	MOAK	FIGURE 46
DATE:	11/23/68	

$$\frac{\text{PHOTOCELL 1}}{\text{PHOTOCELL 2}} = \frac{\text{SERIES R} + \text{A}}{1000 - \text{A}}$$


PHOTOCELL 1
PHOTOCELL 2
HEWLETT PACKARD POWER SUPPLY
DVM
SERIES R VARIED
(HEATHKIT RESISTANCE BOX)
10 TURN POT, READABLE TO NEAREST 1/1000
(100K)
A
1000 - A

COMPLETED:	FERGUSON	DETECTION CIRCUIT
DATE:	5/16/64	
DRAWN:	MOAK	FIGURE 47
DATE:	11/23/68	

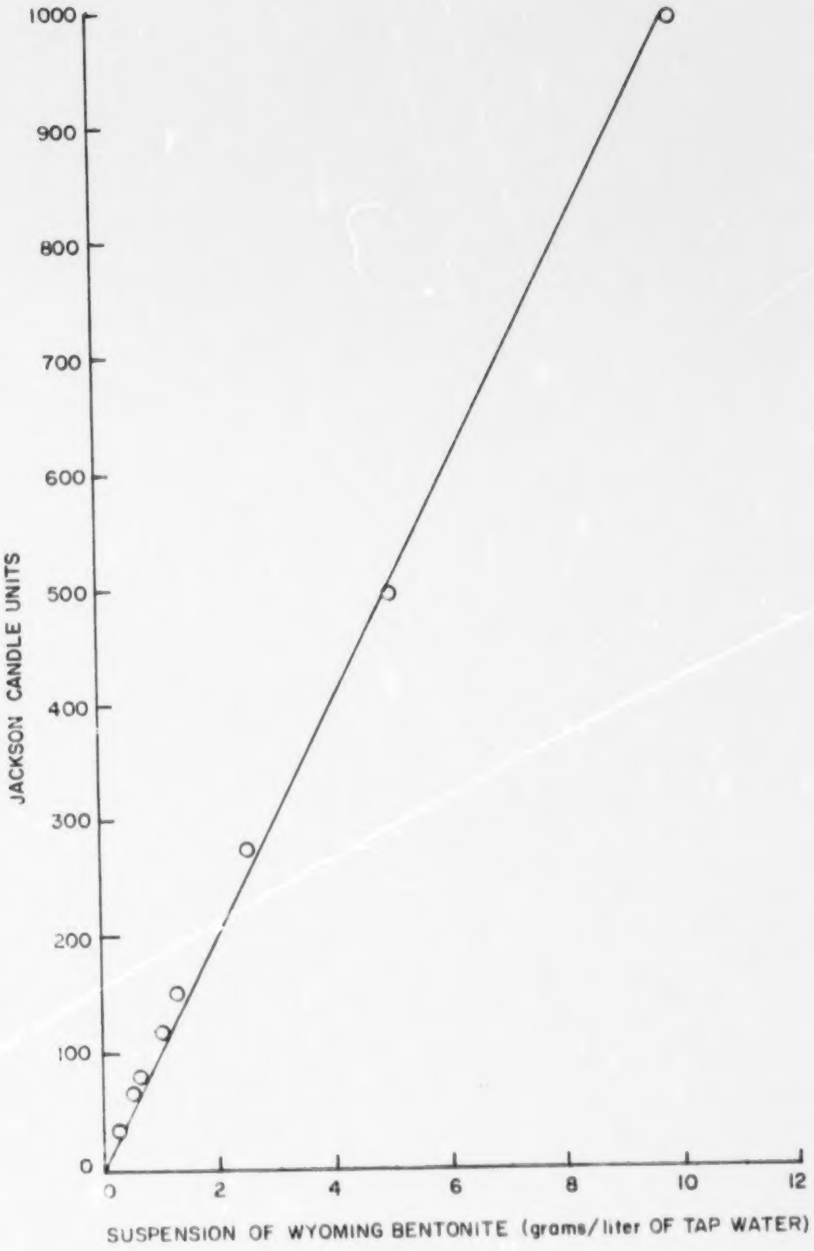


FIGURE 48 A

CALIBRATION CURVE – SUSPENSION OF WYOMING BENTONITE USED IN STANDARD JACKSON CANDLE TURBIDIMETER

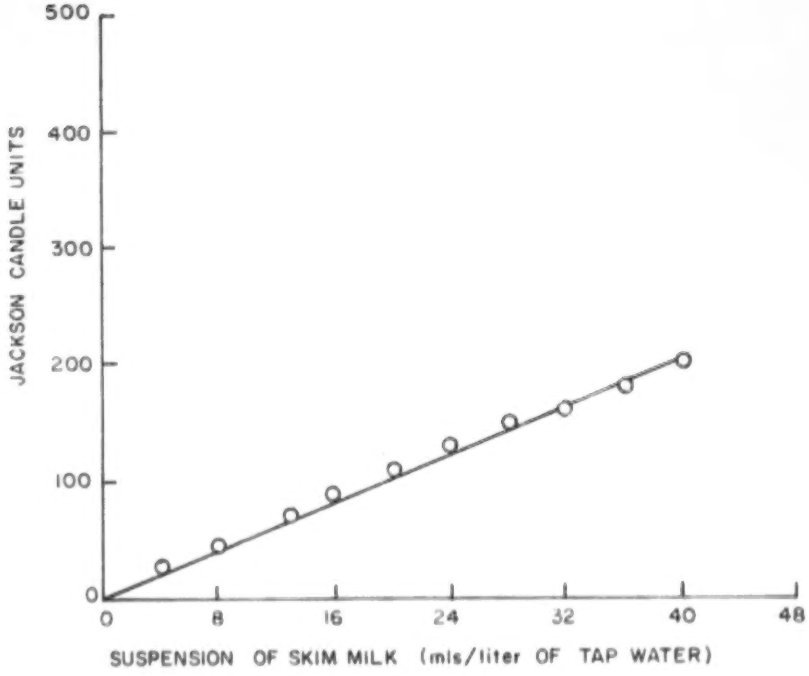


FIGURE 48B

CALIBRATION CURVE — SUSPENSION OF SKIM MILK USED IN STANDARD JACKSON CANDLE TURBIDIMETER

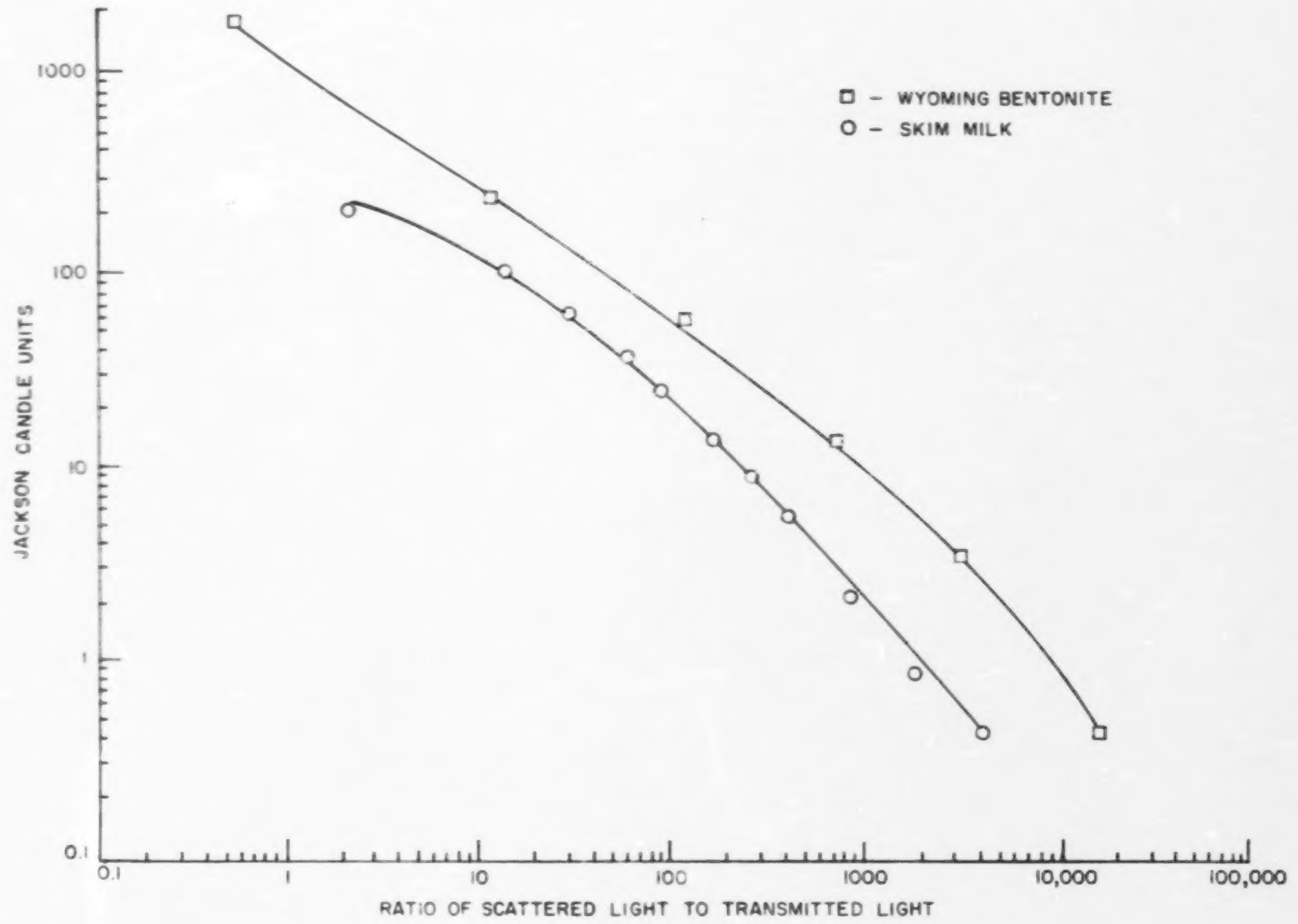


FIGURE 49

JCU VS RATIO OF SCATTERED LIGHT TO TRANSMITTED LIGHT FOR TWO DIFFERENT SUSPENSIONS

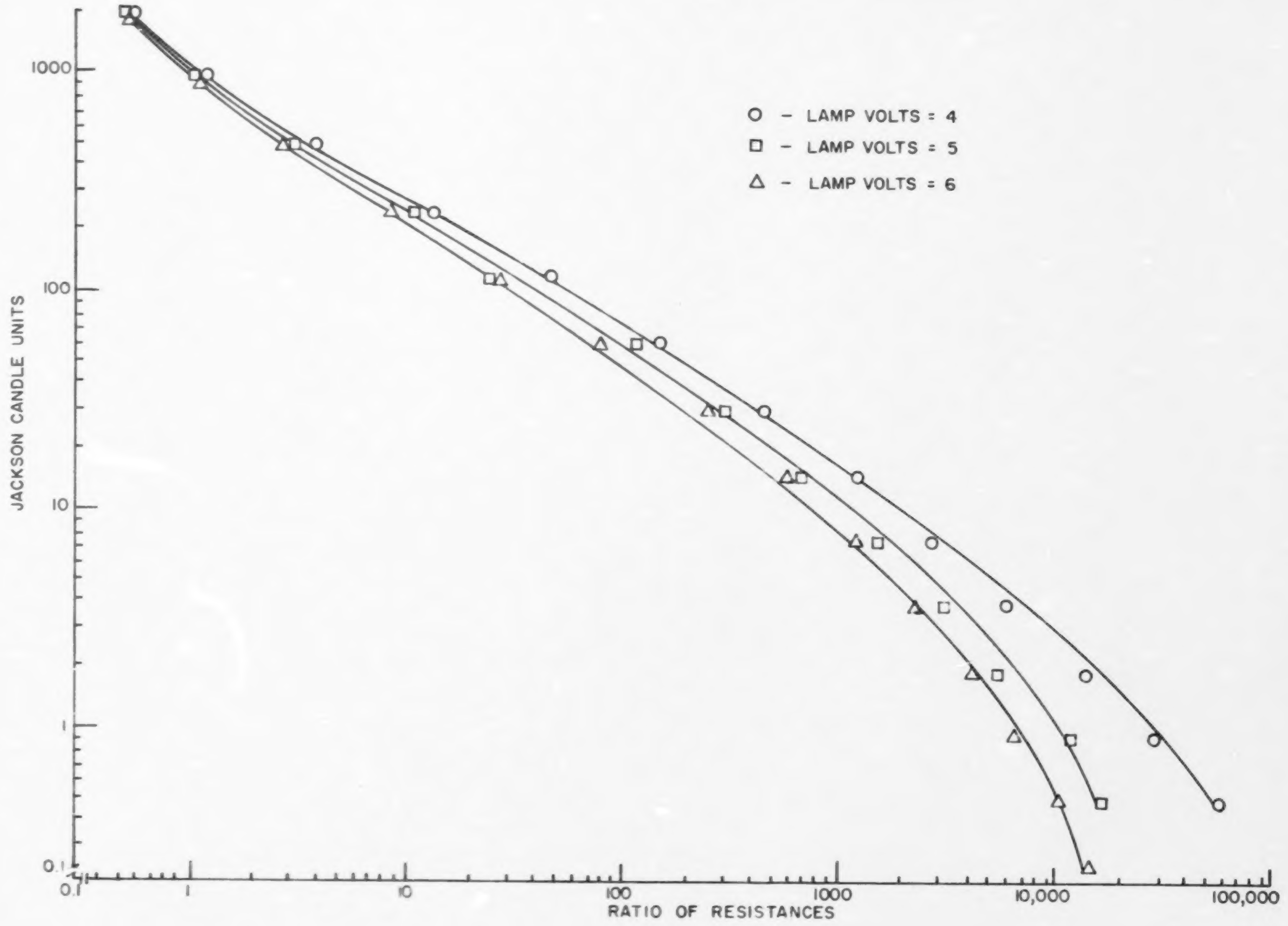


FIGURE 50

STABILITY OF MEASUREMENT IN RELATION TO SOURCE LAMP VOLTAGE CHANGE

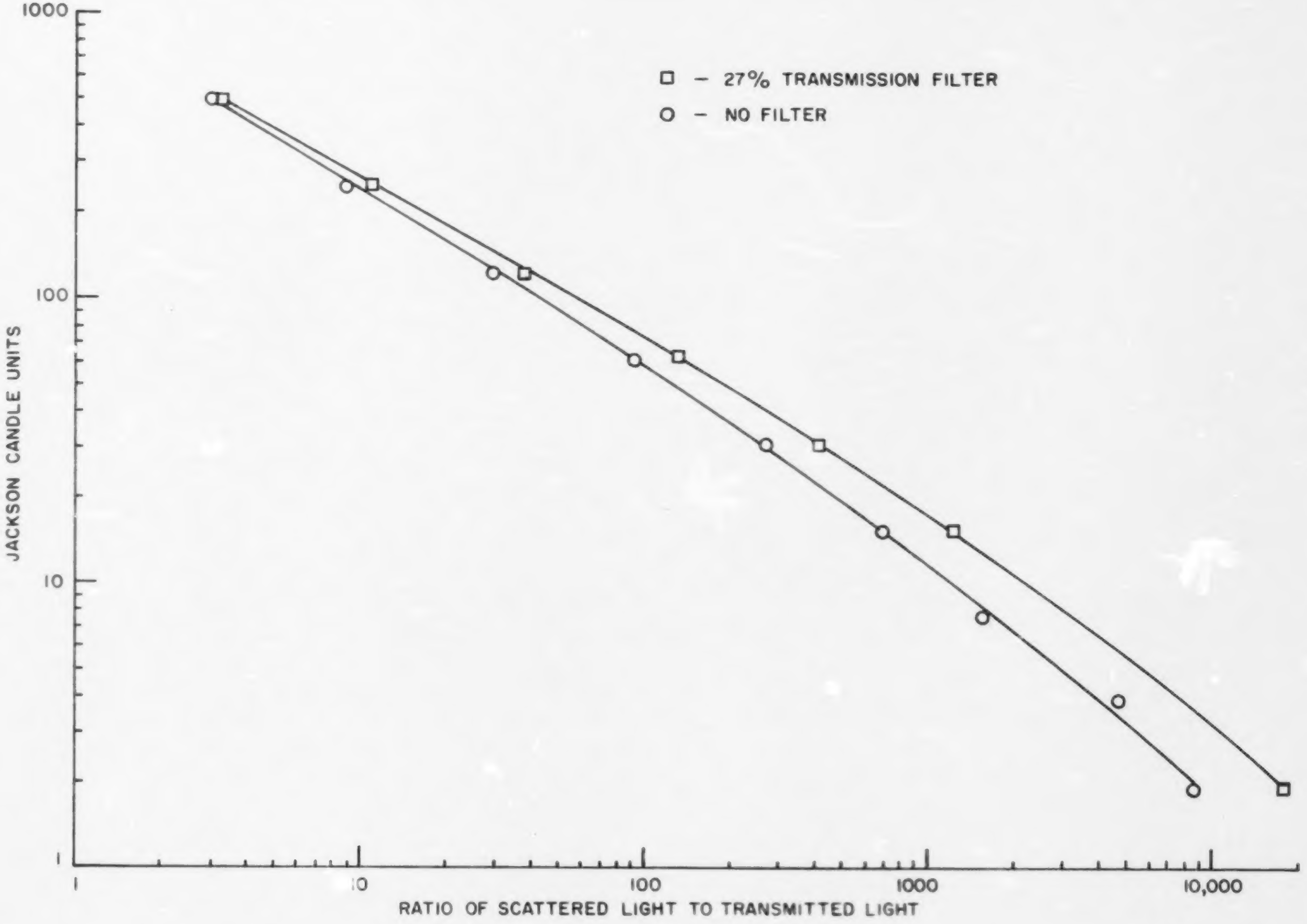


FIGURE 51

STABILITY OF MEASUREMENT IN RELATION TO FOULING OF ENTRANCE WINDOWS

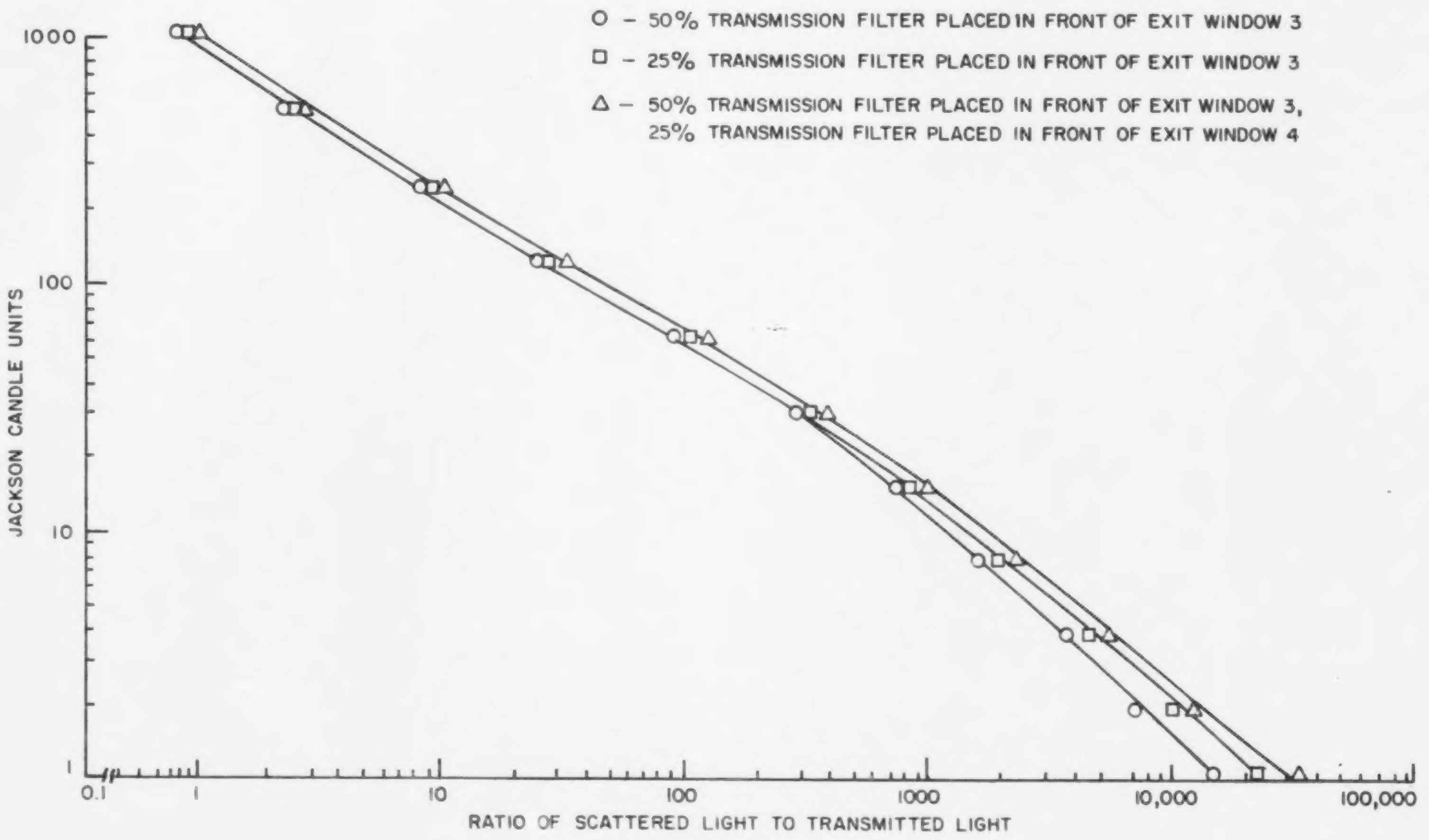


FIGURE 52

STABILITY OF MEASUREMENT IN RELATION TO FOULING OF EXIT WINDOWS

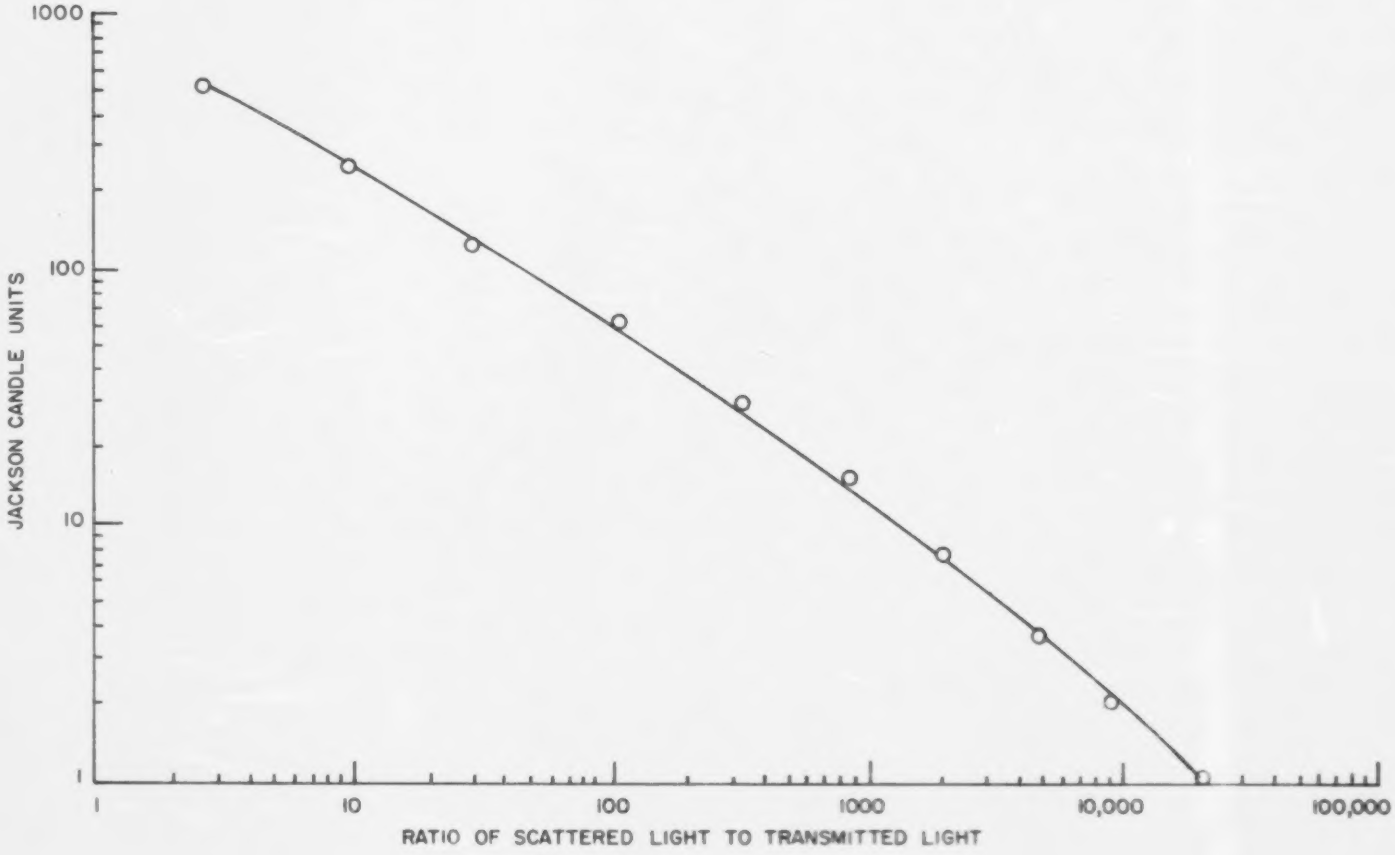


FIGURE 53

STABILITY OF MEASUREMENT IN RELATION TO CHANGE IN DETECTOR POWER SUPPLY

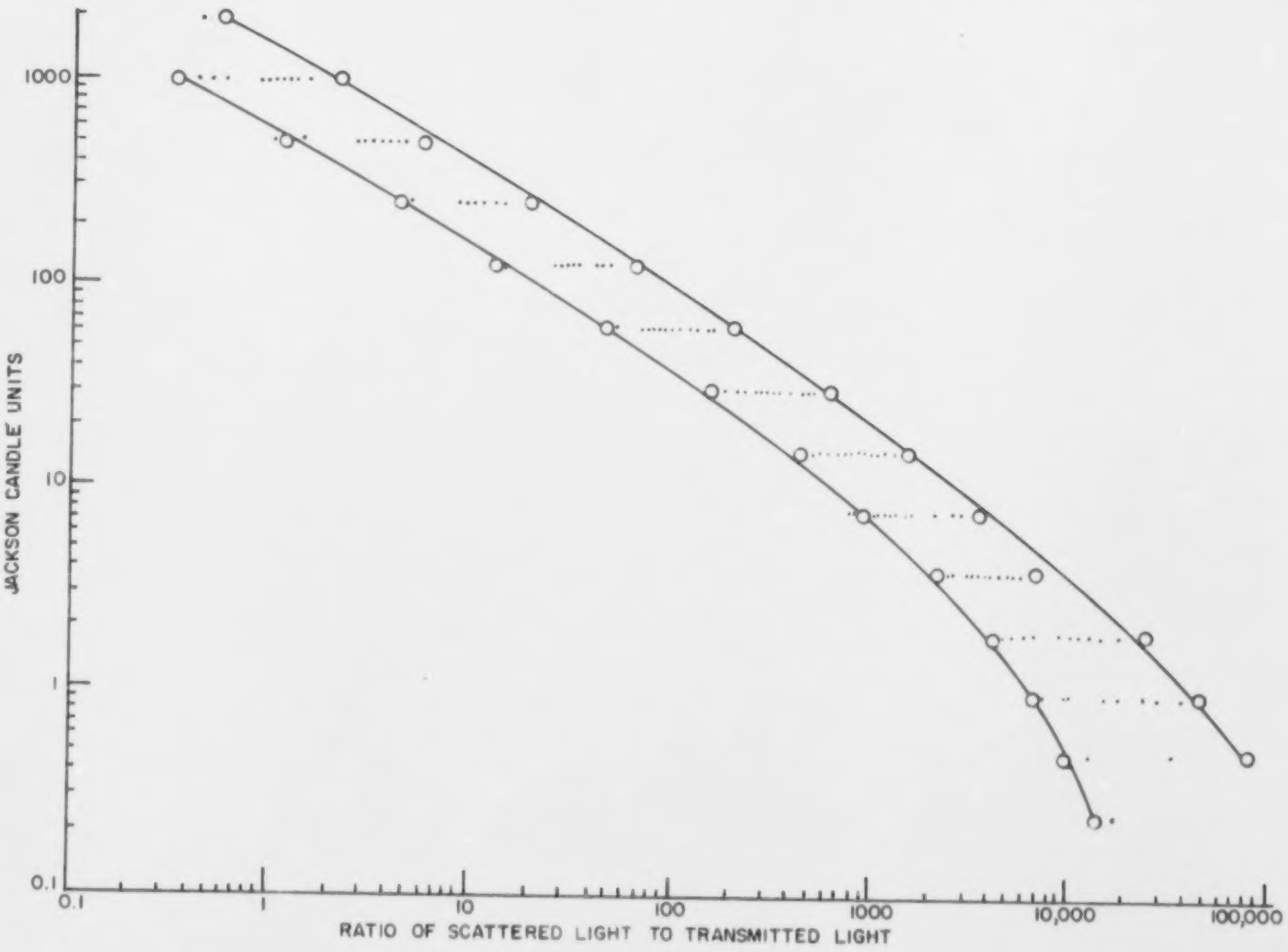


FIGURE 54

EACH INDIVIDUAL RATIO PLOTTED VS JCU

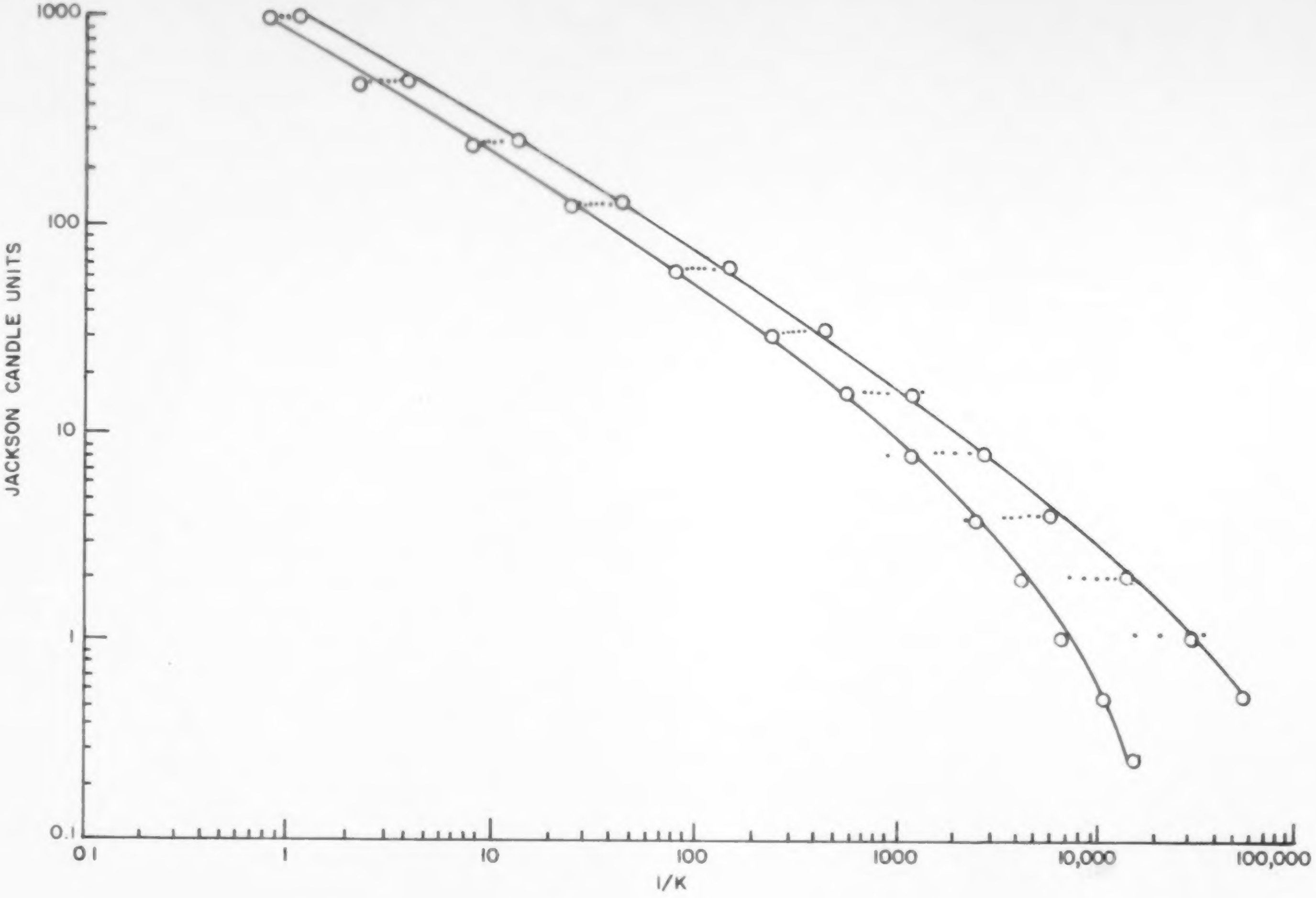


FIGURE 55

SQUARE ROOT OF PRODUCT OF INDIVIDUAL RATIOS (I/K) VS JCU

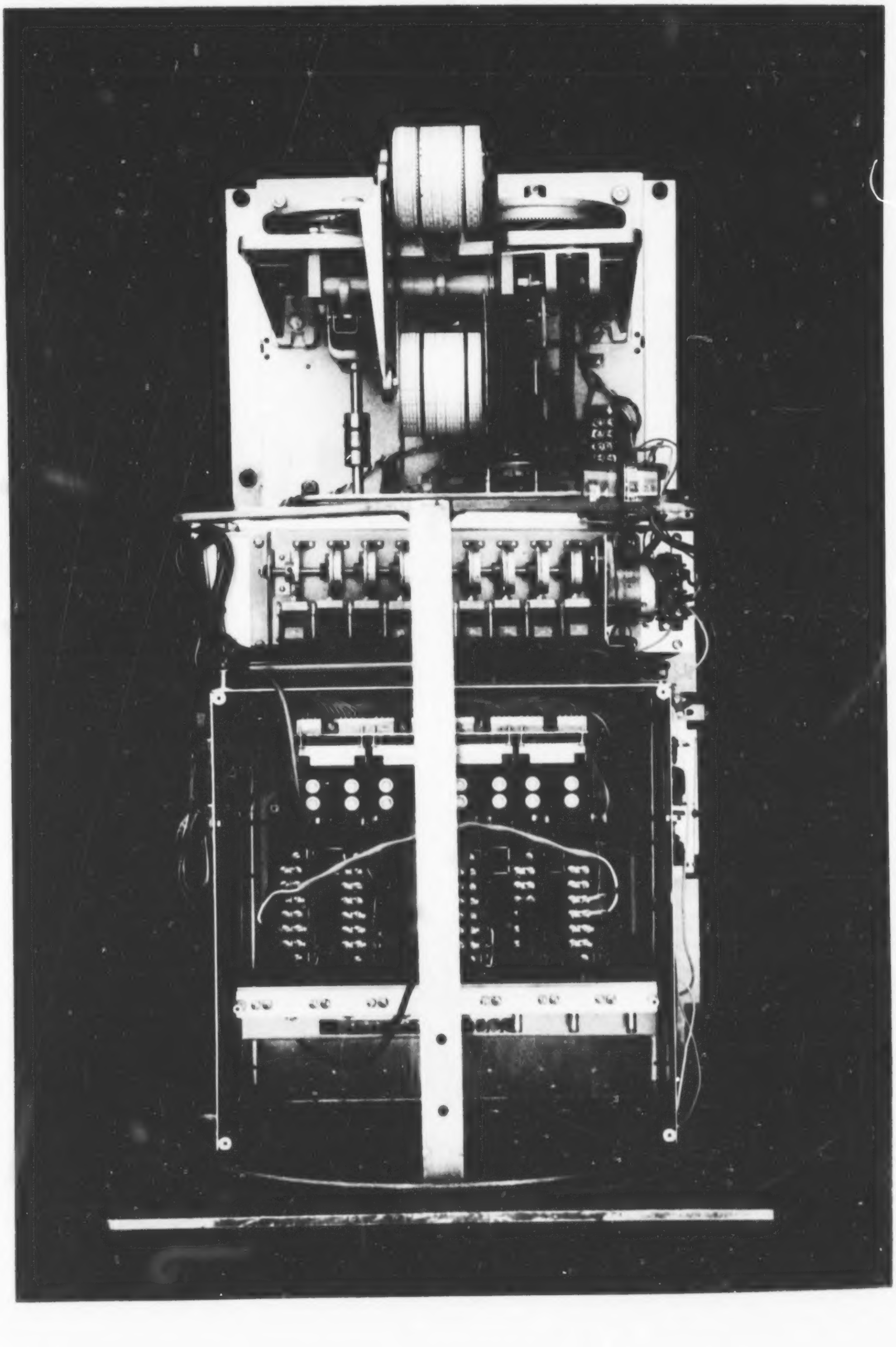


Figure 56. Electronics Package

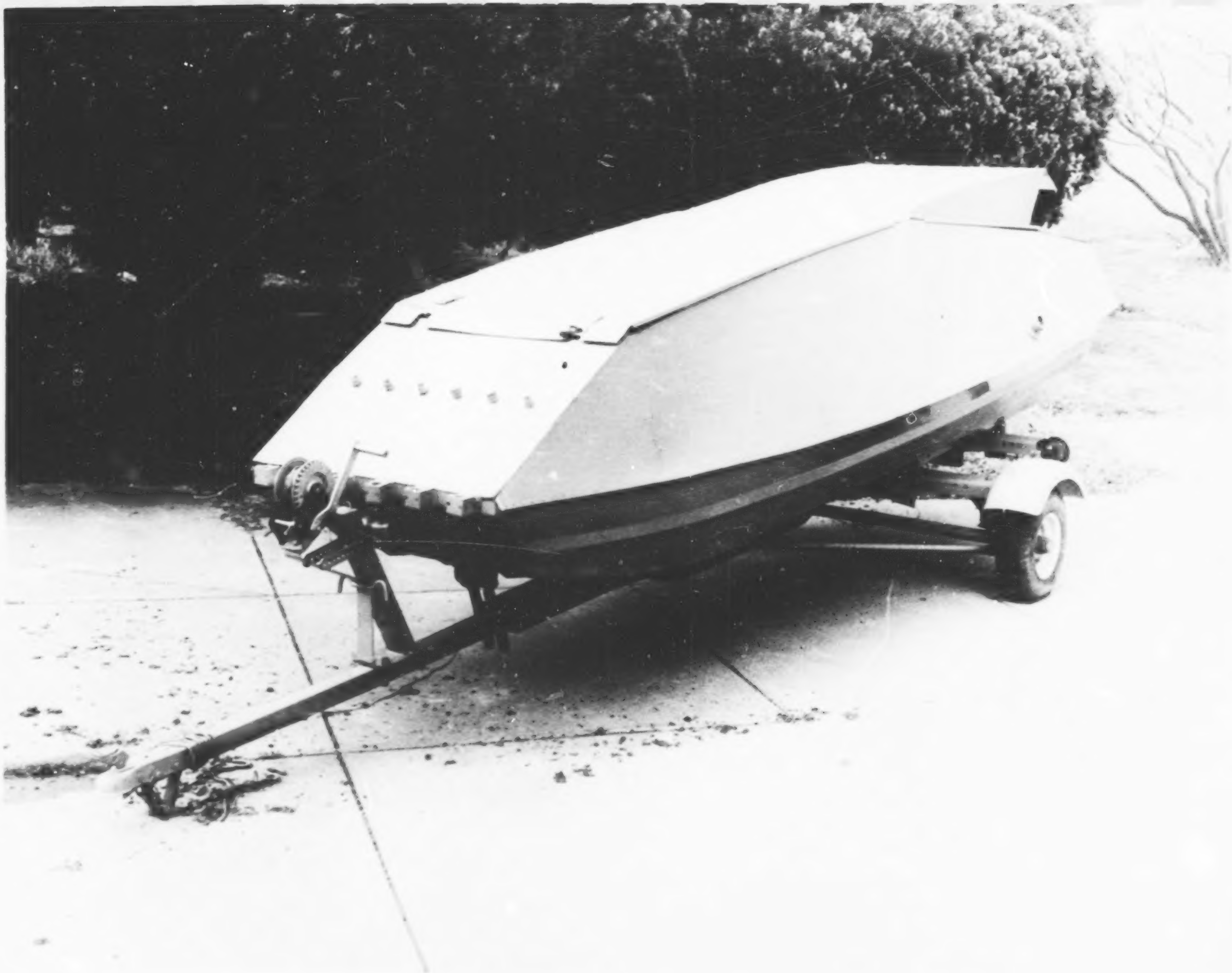


Figure 57. Mobile Monitor